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CATION-EXCHANGE PRETREATMENT STUDIES FOR LA VERKIN SPRINGS

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John W. Kaakinen

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16. ABSTRACT

The main purpose of the cation-exchange experiments on LVS (La Verkin Springs) water was to obtain feasibility data for the pretreatment removal of calcium from desalting feed water or cooling tower makeup water to prevent gypsum-scale formation when achieving high rates of water use. In field tests at the LVS site, a 30-L/min-capacity IX (ion-exchange) pilot plant softened the feed water to – and thus prevented gypsum scaling in – an ED (electrodialyzer) at desalting recoveries of up to 92 percent. The ED reject contained ample sodium to regenerate the IX without additional chemicals. After some process optimization, specific calcium resin capacities exceeded 1.0 eq/L with a common gel-type sulfonated styrene-divinyl-benzene cation-exchange resin, 8 percent crosslinked. Because the ED reject contained sulfate, special techniques were needed to prevent gypsum-scale accumulation in the IX system (1) the use of recycled regenerant preceding fresh reject-brine regenerant to lower the level of calcium-sulfate supersaturation, and (2) high regeneration flow rates and a packed resin bed to minimize the residence time of regenerant in the resin bed. IX experiments also were done in the laboratory using synthetic solutions to simulate LVS water compositions. The laboratory experiments provided data which agree with field test results but extend the number and ranges of the process variables to better characterize the IX process. The IX equilibrium resin capacity, the initial exhaustion leakage concentrations, and the exhaustion breakthrough curve were modeled to help predict IX performance for different water compositions and operating conditions. The success of the LVS IX tests verifies previous projections. That is, cation-exchange pretreatment with waste-brine regeneration is a preferred process compared to more expensive chemical-addition processes such as lime-soda softening to pretreat saline water (at sites such as LVS) to achieve high recovery in desalting or in saline cooling water usage while lowering the brine disposal volume.

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John W. Kaakinen

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Chemistry, Petrography, and Chemical Engineering Section
Applied Sciences Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

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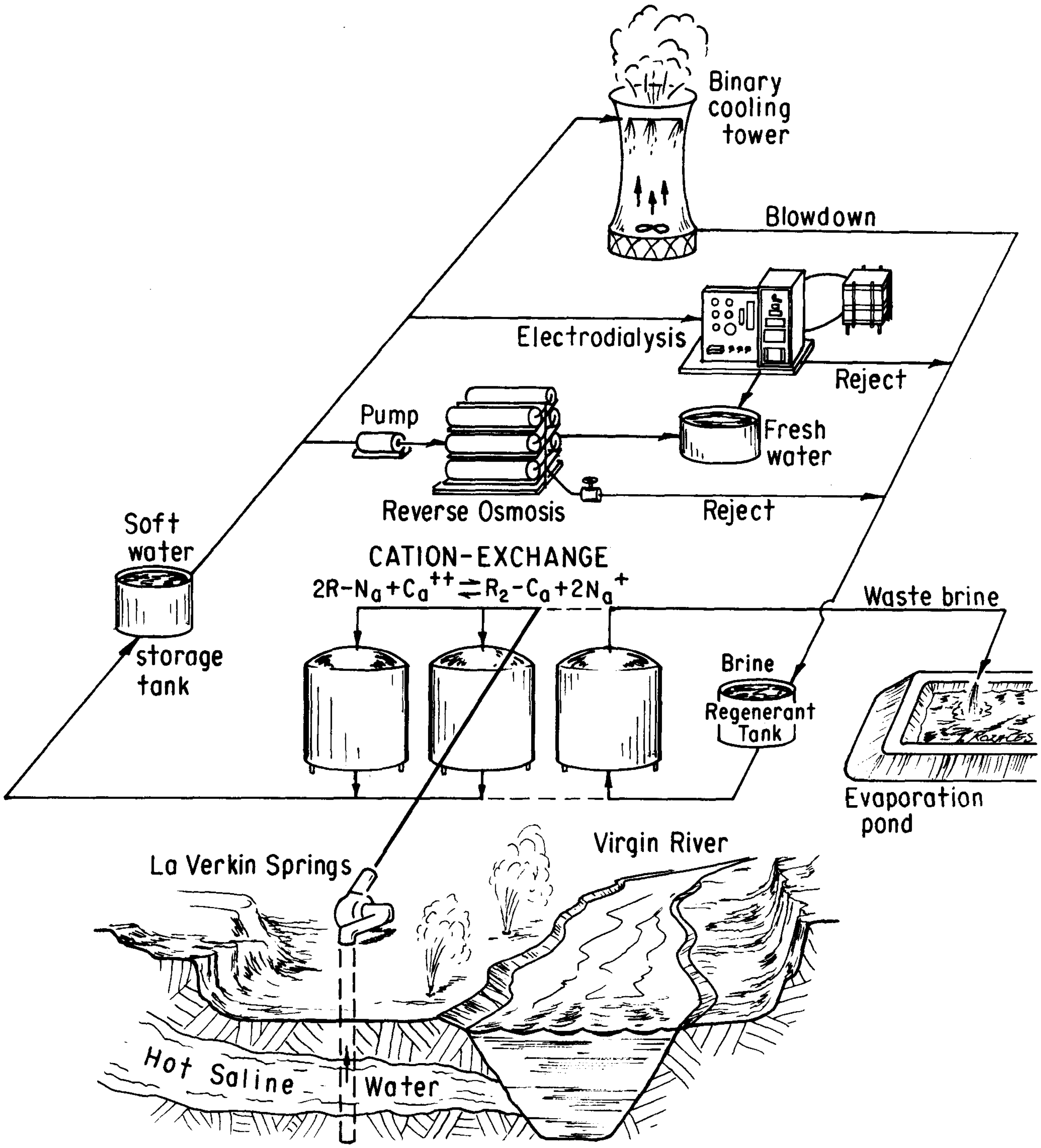

Frontispiece. – Cation-exchange pretreatment studies for La Verkin Springs, Utah.

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INTRODUCTION

The Bureau of Reclamation has studied methods for lowering the salinity of the Colorado River by keeping saline water sources from entering the river [1].* The Bureau has been determining whether some of these saline water sources could be used as a feed water for making freshwater by desalination or as makeup for wet cooling towers operating with saline water. Maximum volume recovery of desalted product water from a saline feed water source is a requirement of a desalting process where there is a shortage of feed water and the onsite disposal of the desalting reject-brine volume is necessary. In many instances of inland brackish water desalting, brine disposal by methods like deep-well injection or evaporation ponds is the dominant cost. Thus, by minimizing the brine volume requiring disposal and maximizing the product water volume, high-recovery desalting can be more economically and environmentally feasible.

The LVS (La Verkin Springs) is a saline water source which deposits considerable salt in the Colorado River [2]. La Verkin Springs is located in southwestern Utah on the Virgin River. The springs flow at 0.326 m^3/s and contain a concentration of about 9.7 kg/m^3 in TDS (total disolved solids). Salts are deposited at nearly 100 000 tonnes per year to the Colorado River system. The water temperature leaving the springs is about 40 °C. Typical raw and partially pretreated water compositions for LVS are listed in table 1 [3].

The feasibility of alternative methods for preventing the LVS salts from entering the river have been studied [2]. Water desalination would provide a needed source of freshwater. A high recovery of product water flow from the feed flow would be necessary to minimize the volume of reject brine requiring disposal, which is a major cost. However, even with high recovery, the cost of desalting LVS is not feasible at present. Alternatively, the LVS saline water could be used as a source of cooling water provided that the blowdown or concentrated waste stream from the cooling tower were not discharged into the Virgin River.

Many brackish waters (as that from LVS) require pretreatment to keep sparingly soluble salts such as silica, calcium carbonate (calcite), calcium sulfate (gypsum), strontium sulfate, and barium sulfate from precipitating on equipment surfaces as the salts are concentrated. This can occur either in desalting equipment or in evaporative cooling towers when the salts become supersatured. Generally, formation of scale in the equipment causes blockages of flow and other serious operational problems. Cation exchange is an economic process for softening (the removal of multivalent cations; i.e., calcium, strontium, and barium, that form sparingly soluble salts with sulfate) when the reject brine from a desalting unit or blowdown from a cooling tower provides the sodium for regenerating the cation exchanger. A process other than IX (ion exchange), for example, high-lime treatment, is needed to remove silica, if required.

The raw well water from LVS contains considerable calcium which, with the sulfate, forms gypsum precipitate at desalting recoveries above about 23 percent according to table 1 data. Because of carbonate water chemistry and the fact that the raw water contains considerable carbon dioxide gas that effervesces as the underground spring water contacts the atmosphere, calcium carbonate precipitates as the pH rises with the loss of the dissolved carbon dioxide. Bubbling air through the raw well water (aeration) speeds the release of the carbon dioxide and reduces the dissolved calcium concentration through the precipitation of calcium carbonate. Adding lime to the aerated water can remove additional calcium and bicarbonate until the bicarbonate is exhausted, which is called partial lime softening. At

Table 1. — *Typical compositions of raw and partially pretreated well water at La Verkin Springs. [3]*

	Units	Raw water	Aerated water	Lime-softened water
Characteristics				
pH	unit	6.0	7.4	9.5
TDS by summation	mg/L	9 243	8 754	8 430
TDS by evap. at 105 °C	mg/L	9 507	9 054	8 530
Summation of cations	meq/L	154	143	131
Summation of anions	meq/L	154	145	133
Conductivity at 25 °C	µS/cm	14 800	14 100	12 800
Maximum recovery*	%	23	37	50
Constituents				
Calcium	mg/L	820	600	420
Magnesium	mg/L	150	144	128
Sodium	mg/L	2 220	2 220	2 300
Potassium	mg/L	182	181	180
Strontium	mg/L	10	6	5
Barium	µg/L	90	**	**
Iron	mg/L	< 0.1	< 0.1	< 0.1
Manganese	µg/L	13	**	< 50
Free carbon dioxide	mg/L	750	18	0
Bicarbonate	mg/L	1 266	795	0
Carbonate	mg/L	0	0	26
Sulfate	mg/L	1 860	1 850	1 850
Chloride	mg/L	3 345	3 330	3 340
Silica	mg/L	40	30	15

* Maximum desalting recovery while avoiding calcium-sulfate precipitation at 20 °C.
** Data not available.

* Numbers in brackets refer to entries in the Bibliography.

LVS (according to table 1), the maximum desalting recovery with lime treatment is about 50 percent, not adequate for a practical desalting plant at LVS. Further calcium removal by lime-soda softening requires the addition of soda ash, which is an expensive chemical relative to lime. At LVS, IX was selected for experimental study because it — when coupled with desalting above 80 percent recovery where the desalting reject provides the IX regenerant — was shown to be less expensive than the alternative softening process, lime-soda softening coupled with about 70 percent recovery desalting [2].

This report describes field and laboratory experiments and modeling of the IX pretreatment process as applied to LVS. A brief report of this work was presented earlier [4]. Other reports contain the IX field data without much data analyses or conclusions [5, 6] and details of the testing of the electrodialyzer used to produce the reject-brine regenerant [7]. Testing at LVS of other processes including aeration, lime, and lime-soda softening, reverse osmosis, and a spiractor are outlined in two of these reports [5, 6].

PURPOSES AND EXPERIMENTAL PLAN

The overall purpose of the LVS IX field tests was to obtain feasibility data for the IX pretreatment process applied to LVS, although the results are applicable also to other sites with consideration given for different water compositions. During 4 months, different IX operating conditions and procedures were tested at LVS to try to optimize IX performance. The IX data were studied to determine what operating parameters (at LVS) yield maximum values for the specific resin capacity for calcium removal (the milliequivalents of calcium absorbed per volume of cation-exchange resin per cycle). Another process parameter more indicative of IX equipment capacity requirements defined here is called the *time-weighted resin capacity* (the specific resin capacity for calcium removal divided by IX cycle duration). The *time-weighted resin capacity* is important because, in an IX plant, it is inversely proportional to the amount of cation-exchange resin required, which is often the largest capital cost in an IX plant. Also, because the use of sulfate-containing reject brine to regenerate the cation-exchange resin can cause gypsum scaling in the resin bed — unless special methods are used to control the problem — another dependent variable, the intensity of gypsum scaling in the resin bed and piping was studied, which was observed qualitatively in the field testing.

In addition to field tests at LVS site, laboratory IX experiments at the E&R Center (Engineering and Research – Bureau of Reclamation) on waters synthesized to simulate LVS compositions were performed. Laboratory experiments were done for the following purposes:

1. To study IX performance responses to process variables that were not tested at the LVS site,

2. To determine to what extent such laboratory experiments could substitute for much more expensive field testing or to obtain IX data, and

3. To provide data to model the cation-exchange pretreatment process and, thereupon, to minimize required experimentation in the future for the water compositions at LVS and other sites.

Different operating procedures for the IX laboratory experiments were used than for the field tests. During the laboratory experiments, the exhaustion and regeneration of the cation-exchange resin column were done to nearly complete equilibrium between resin and solution rather than stopping them at a maximum exhaustion effluent concentration (calcium breakthrough concentration) or by a fixed volume of solution as had been done in the field experiments. The synthetic LVS solutions were cationic chlorides to prevent the variable of gypsum precipitation during regeneration, which can occur with sulfate-containing regenerant solutions to remove calcium from the cation-exchange resin. This report contains comparisons between the laboratory results and the field results.

Two simplified models were developed from theory to describe the IX process. Values for the parameters were determined from the models by fitting statistically the model equations to the IX data. The purpose of the modeling effort was to provide a descriptive tool of the IX process for allowing prediction of IX performance with different water compositions and at different operating conditions without the need for experimentation, or at least with a minimum of experimentation.

One of the models predicts the equilibrium resin composition and the initial effluent water composition during exhaustion. The other model describes the exhaustion effluent composition curves assuming that the rate of cation exchange between the resin and solution is controlled by the mass-transfer resistance of the "liquid film" surrounding the resin beads and that the absorption of hardness cations (calcium and magnesium) by the resin from solution is greatly preferred over the absorption of sodium. It was not possible to derive a model for the regeneration step because of time; however, it is outlined in this report how one would approach the development of a regeneration model.

CONCLUSIONS AND RECOMMENDATIONS

The success of testing LVS verifies previous projections that IX pretreatment can help at LVS and at similar saline water sites to:

1. Achieve 90 percent or greater product-water-recovery rates from desalination plants while minimizing the brine-disposal waste stream,

2. Use saline water as makeup to evaporative cooling towers while minimizing the brine-disposal volume,

3. Minimize the size of evaporation ponds needed to dispose of the waste brine,

4. Reduce pretreatment costs compared to alternative processes such as lime-soda softening,

5. Facilitate the operation and performance of solar salt-gradient ponds by increased water and regenerant-brine recycling and by reduced overall system costs.

Specific *Conclusions* regarding the IX pretreatment process were made from the LVS IX experiments and modeling.

1. The cation-exchange pretreatment process was extremely successful in removing over 90 percent of the calcium and strontium from La Verkin Springs water to allow demonstrated desalting recoveries up to 92 percent by an electrodialyzer while avoiding any precipitate formation in the concentrate stream. The reject brine from the electrodialyzer was ample regenerant for the IX. The IX process could pretreat LVS water equally well for other desalting processes or a wet binary cooling tower in which the waste brine would provide regenerant for the IX. Specific resin capacities for calcium removal were nearly double at LVS what they were at YDTF (the Bureau's Yuma Desalting Test Facility, Arizona) for the same IX process. The high resin capacities at LVS are attributed to the high sodium concentrations and relatively large volumes of the reject-brine regenerant. The fresh reject brine was so effective by itself at LVS that recycled regenerant was not needed to help regenerate the cation-exchange resin. However, use of the recycled regenerant did aid in moderating the rate of formation of gypsum (calcium-sulfate dihydrate) scale in the resin bed and effluent piping, which resulted from regeneration with the sulfate-containing reject brine.

2. At LVS, the accumulation of gypsum scale in the piping carrying the regeneration effluent caused maintenance problems by blockages in flow. Higher specific resin capacities for calcium removal were highly correlated with greater rates and amounts of gypsum precipitating in the IX-resin bed and effluent piping during regeneration. In qualitatives agreement with the published kinetics of gypsum precipitate formation, gypsum-scale accumulation in the resin bed increased with the calculated magnitude of calcium-sulfate supersaturation levels in the regeneration effluent and with the residence time for regenerant solution in the IX-resin bed. The gel-type, cation-exchange resin tested at LVS, apparently because of its smooth, spherical surface and because of electrostatic repulsion of sulfate anion, shed calcium-sulfate scale more easily than the macroreticular resin, which contains porous channels, used at the YDTF.

Restraining the resin bed during upflow regeneration and increasing the regeneration flow rate decreased the amount of gypsum precipitate retained in the resin bed, primarily because the regenerant residence time for the packed bed was only about one-fourth that duration for the fluidized bed. The observed benefit of a packed bed to lower gypsum formation in the bed conflicts with previous conclusions of others that a fluidized bed was necessary to prevent the accumulation of gypsum scale in the bed, although the previous investigations did not test a packed bed system like the one tested at LVS. Gypsum-scale accumulation in the regeneration-effluent piping was prevented where there was common piping for regeneration effluent and exhaustion feed, whereby the feed water redissolved any precipitate formed in the preceding regeneration. Recycling regenerant provided large volumes of weaker regenerant, which was used preceding fresh reject brine to decrease the peak level of calcium-sulfate supersaturation in the regeneration effluent. Separating the regeneration-effluent volume into selected fractions for regenerant recycling could provide any desired lower concentration of sodium in the recycled regenerant to blunt the initial calcium-sulfate supersaturation peak in the regeneration effluent. Such use of graded recycled regenerant would limit the gypsum-formation rate to control scaling in the IX system without wasting water, which would lower the overall water recovery of the IX-desalting system.

3. At LVS, no problems of microbiological fouling from the IX product water were observed as had occurred at the YDTF. The control of the microbiological growth at LVS was attributed primarily to rechlorination of the IX product.

4. The laboratory experimentation yielded IX resin capacity data that was comparable to those capacities obtained in the field experiments. However, because synthetic chloride solutions simulated LVS cationic water compositions the laboratory experiments did not include any gypsum precipitation during regeneration. The total cost of the laboratory experiments was less than one-tenth of the cost of the field IX experiments. A greater amount of information on the behavior of the IX process was obtained by extending the influent-solution volumes of exhaustion and regeneration to where ionic equilibrium between the influent solutions and IX resin was approached. More common experimental practice, which directly simulates commercial IX operation, is to restrict volumes by a set maximum calcium breakthrough concentration during exhaustion and a practical brine volume during regeneration. Yet, data collected — while using the extended exhaustion and regeneration volumes — were successfully interpolated to include the exhaustion step terminated at practical calcium breakthrough concentrations.

5. In the laboratory experiments, a range of water temperatures of 15 to 35 °C had no significant effect upon the cation-exchange equilibrium or the mass-transfer rates including the shapes of the exhaustion-breakthrough curves. In the field experiments, increasing temperature did increase the rate of gypsum precipitation in the IX system during regeneration because the reject-brine regenerants contained sulfate. Thus, the present application of IX temperature need only be considered important for gypsum formation during regeneration but not for the cation-exchange process itself.

6. Laboratory experimental results confirm that the IX process without preceding lime softening can effectively remove the calcium and other multivalent cations (which doesn't include silica) required for scale-free, high-recovery desalting of aerated LVS well water. The resin volume needed to soften aerated LVS well water would be about 29 percent greater than the resin requirement to soften further by IX the water pretreated with lime. The 29-percent larger IX plant would be substantially cheaper than the inclusion of the additional lime-softening pretreatment step. However, without lime treatment to remove silica, the silica in LVS water poses a potential scaling problem, which needs to be investigated further at recoveries above 80 percent in processes that concentrate silica, such as reverse osmosis, distillation, and wet binary cooling towers. Because electrodialysis does not concentrate un-ionized silica, there definitely would not be a silica-scaling problem at LVS with electrodialysis whether or not the silica were removed.

7. The success of modeling the present IX process was mixed. Qualitatively, the modeling was very successful in better understanding and describing the IX process, especially considering this was the Bureau's first attempt at IX modeling. Quantitatively, the models need more development including more IX data for their confirmation to provide more accurate estimates.

A. Equilibrium-model estimates of specific resin capacity for calcium removal were low relative to experimental values; still, they were judged useful if experimental data is unavailable.

B. Equilibrium-model estimates of calcium and magnesium concentrations in the initial effluent from exhaustion were low relative to experimental values, which is attributed primarily to hydrodynamic aspects of flow through the porous resin bed not included in the equilibrium model, which includes the assumption of instantaneous chemical equilibrium between resin and solution.

C. For exhaustion of the laboratory IX cycles, the initial bend of the "S" shaped curve of calcium concentration versus throughput volume, which includes the practical range of breakthrough concentrations of calcium, is fit well by a two-parameter exponential equation derived from a liquid-film, mass-transfer model. Mass-transfer coefficients calculated using the model and laboratory data were of the same magnitudes as previously published results and increased with the 1.2 power of flow velocity, which also agrees within experimental error with published values.

Recommendations are made regarding future study and further optimization of the ion-exchange pretreatment of LVS and other saline waters for desalting feed water or cooling tower makeup.

1. The use of weaker recycled regenerant solutions to lower the peak level of calcium-sulfate supersaturation in the regeneration effluent needs to be detailed in concept, confirmed in laboratory experiments, and later demonstrated in the field.

2. Likewise, to prevent gypsum-scale accumulation in the regeneration effluent piping, development and demonstration is necessary regarding the rinsing by exhaustion feed water of the midcolumn collector that collects regeneration effluent and helps to maintain a packed bed.

3. The equilibrium model needs to be refined from more complete cation-equilibrium data from the laboratory for the system DOWEX® HCR-W2-calcium-magnesium-sodium. Such data has been collected in the Bureau's laboratory and includes development of an improved equilibrium model in a parallel study of the present work.

4. Future field experiments of ion exchange should include, but not necessarily be limited to, exhaustion and regeneration to near chemical equilibrium between solution and resin. This will provide more information per IX cycle by completely characterizing the effluent-concentration histories, which will better define IX behavior for improved IX performance modeling and prediction, with little increase in the collected data and associated costs.

5. The liquid-film or similar models for the exhaustion-effluent-concentration history should be expanded to include three and possibly four cationic components, which will require a finite-difference, numerical solution using a computer.

6. Additional column experiments using a range of calcium, magnesium, and sodium concentrations in the exhaustion-feed water and regenerant solutions will be needed to develop and confirm the multicationic mass-transfer model in 5. above.

7. The regeneration step should be modeled to include the effect of limited regenerant volume and partial regeneration on exhaustion performance. The model of regeneration should include unfavorable equilibrium relationships (proportional patterns of effluent-concentration histories) with possible corrections, if necessary, by including mass-transfer-rate limitations.

8. Further work is needed to define accurate silica-concentration limits prior to the onset of silica precipitation of LVS aerated water. This information will determine whether cation exchange can completely replace lime treatment as a pretreatment at LVS for processes that concentrate the silica present in the well water to concentration factors above 4.

BACKGROUND

IX Process Description

Utilizing the reject desalting brine or cooling tower blowdown to regenerate a fixed bed cation-exchange softener often requires different procedures [8 to 11] than when using common sodium-chloride regenerant solution [12]. These differences listed in table 2 are required because of the occurrence of supersaturated calcium sulfate in the effluent of regeneration with sulfate-containing brines and to the limited volume of regenerant (reject brine) available per IX cycle.

The individual steps of a typical IX cycle using desalting-reject-brine regeneration and recycled regenerant in table 2 have the following purposes.

Exhaustion. – Feed water is softened (calcium and magnesium ions are absorbed) by downward flow through the cation-exchange-resin bed. Exhaustion of the resin continues until the calcium concentration in the effluent increases to a set breakthrough concentration, which is determined by the maximum allowable calcium in the effluent while avoiding gypsum precipitation. Then exhaustion is terminated.

Exhaustion is the only step in the IX cycle when water is being pretreated. All other steps in the cycle prepare the resin for this softening step. Exhaustion also sometimes is called "service."

Drain 1. – Feed water is removed from the resin bed to avoid excessive dilution of recycled regenerant in the following step.

Regeneration 1. – Recycled regenerant from a storage tank is used for an upflow backwash and partial regeneration. This backwash removes suspended particles filtered from the feed water during exhaustion and reclassifies the resin beads by particle size with increasingly larger particles closer to

Table 2. – *Comparison between an IX softening cycle using NaCl regeneration and a cycle using desalting reject-brine regeneration*

Mode	Input	Output	Flow direction
A. NaCl regeneration used in standard cation-exchange softening			
Exhaustion	Feed	Product	Down
Backwash	Feed	Waste	Up
Regeneration	NaCl solution	Waste	Down
Drain	Vent or air	Waste	Down
Slow rinse	Feed	Waste	Down
Fast rinse	Feed	Waste	Down
B. Regeneration with desalting brine for high recovery pretreatment[1]			
Exhaustion	Feed	Product	Down
Drain 1	Vent or air	[1]Waste	Down
Regeneration 1	Recycled regenerant	Waste	Up
Regeneration 2	Recycled regenerant	Used regenerant	Up
Regeneration 3	Fresh desalting reject	Used regenerant	Up
Drain 2	Vent or air	[1]Waste	Down
Rinse (slow)	Feed	[1]Waste	Down

[1] Except for Regeneration 1, waste streams could be recycled by combining them with other process streams to minimize the net wastage of water. The penalty for recycling these streams would be fractionally larger equipment capacity to handle the recycled flow.

the top of the bed and finer resin particles toward the bottom. The effluent of Regeneration 1 is the major process waste stream containing nearly the total volume of reject from the coupled desalting or cooling process when the total reject volume is used to regenerate the IX. Regeneration 1 volume per cycle should match Regeneration 3 volume for steady-state system if there are no other regenerant losses.

Regeneration 2. – Recycled regenerant continues to pass through the resin bed upflow, but the used regenerant is returned to the recycling system for further use.

Regeneration 3. – Fresh reject-brine regenerant passes upflow through the resin bed providing a higher strength regenerant than the recycled regenerant. The effluent is recycled for use in Regenerations 1 and 2.

Drain 2. – The excess regenerant is removed from the resin bed to lower the subsequent rinse volume.

Rinse. – The remaining regenerant is flushed downflow from the resin to provide a high-quality effluent in preparation for the beginning of the exhaustion step of the following cycle.

The LVS field experiments included the cycle above and variations to it. In the laboratory experiments, the exhaustion step was taken beyond a normal breakthrough concentration to approach total equilibrium of the resin with the feed solution.

The average volume of fresh regenerant V_f available per IX cycle from desalting reject is a function of the desalting recovery and the exhaustion throughput volume per cycle. A flow balance between the IX and desalting processes yields V_f as a function of the fractional desalting recovery R and the volume of exhaustion product per cycle V_e according to:

$$V_f = V_e(1 - R) \qquad (1)$$

Supersaturated calcium sulfate in the regeneration effluent is a consequence of the high concentrations of calcium eluting from the cation-exchange resin during regeneration plus high concentrations of sulfate contained in the desalting reject brine. To avoid gypsum (calcium sulfate dihydrate) scaling of the resin bed, the regeneration is carried out with upward flow, countercurrent to downward flow of the exhaustion step, and the upward flow is at a sufficient velocity to fluidize the bed similar to a backwash. Similar methods were developed for the regeneration of IX resins using sulfuric acid [13]. Because the precipitation of gypsum crystals is not immediate but delayed due to the reaction kinetics of gypsum formation [14], the regenerant solution can be passed through the resin bed rapidly enough in many cases that no significant amount of gypsum can accumulate in the bed.

Recycling some of the regenerant (an innovation developed at the University of California [10]) offsets the limited volume of fresh desalting reject made per IX cycle according to equation 1. This limited regeneration volume becomes particularly important with the high-regeneration flow rates used to prevent gypsum accumulation in the resin bed because mass-transfer rates may be insufficient to adequately regenerate the resin in the resulting limited regeneration time.

Recycling the regenerant involves desupersaturation of the calcium sulfate in the used regenerant. This is accomplished by contacting the used regenerant solution with gypsum crystallites in an agitated tank which operates as a batch system [10] or a spiractor which operates continuously [5,6,15]. The seed crystallites are gypsum precipitate retained from previous IX cycles. After stopping the agitator in a batch recycling tank, the gypsum crystals separate from the solution by sedimentation. In a spiractor, the solids-liquid separation occurs because of centrifugal force like that of a cyclone where the fluid is forced along a circular path and the momentum of the suspended particles carries them to the circular wall where they collect and settle out. Because precipitation and settling of gypsum removes calcium and sulfate ions from solution, it also lowers the TDS (total dissolved solids) concentration of the used regenerant. The clear supernatant becomes recycled regenerant and is transferred to a storage tank. Because the recycled regenerant has a lower concentration of sodium, a lower total solution normality, and a higher calcium concentration compared to fresh reject brine, it could remove less calcium from the resin than fresh regenerant and is used prior to fresh regenerant.

Ion-exchange performance to absorb a particular ion is characterized by the *specific resin capacity*, the gram equivalents of the ion absorbed during an exhaustion step of an IX cycle per volume of resin. In the present application, the cation needing removal is calcium. The specific resin capacity for calcium removal q_{Ca} is a complex function of feed and regenerant compositions, total cationic exchange capacity and selectivity of the resin, and IX cycle operating conditions including flow rates, solution throughput volumes, and contact times between solution and resin. The effects of these variables on q_{Ca} are major subjects of this report.

The value of q_{Ca} (in a similar manner q_{Mg}) can be calculated from IX exhaustion performance data using:

$$q_{Ca} = \frac{V_e C^i_{Ca} - \int_0^{V_e} C^o_{Ca}\, dV_e'}{V_{resin}} \qquad (2)$$

where:

q_{Ca} = the specific calcium resin capacity eq/m³,
V_e = the throughput volume of the exhaustion step m³,
C^i_{Ca} = the calcium concentration in the IX feed water eq/m³,
C^o_{Ca} = the calcium concentration in the IX effluent eq/m³, and
V_{resin} = the volume of resin m³.

The integral term in equation 2 generally is estimated numerically from discrete measured points of C^o_{Ca} versus V_e. In the present work, the trapezoidal rule was used.

Because the IX resin is often the greatest capital cost item in an IX plant, it is important for feasibility and design purposes to estimate the amount of resin required to treat a particular flow. Derived from a mass balance of calcium the total volume of cation-exchange resin, V_{resin} in m³, needed to treat an average feed flow, G_{feed} in m³/h, from a feed-calcium concentration of C^i_{Ca} eq/m³ can be calculated from:

$$V_{resin} = \frac{G_{feed}(C^i_{Ca} - C^o_{Ca})\, t_c}{q_{Ca}} \qquad (3)$$

where:

t_c = the duration of the IX cycle in hours.

Thus, when using pilot plant performance to calculate the amount of resin required to treat a given feed flow and calcium removal, it is important to include not only q_{Ca} but also t_c in the calculations. The cycle duration is the sum of the durations of each IX step according to:

$$t_c = \frac{V_e}{G_e} + \frac{V_e(1 - R)}{G_f} + \frac{V_r}{G_r} + t_o \qquad (4)$$

where:

V_e = volume of the exhaustion step m³,
G_e = flow rate of exhaustion m³/h,
G_f = flow rate of fresh regenerant m³/h,
V_r = volume of recycled regenerant m³,
G_r = flow rate of recycled regenerant m³/h, and
t_o = durations of other steps in the cycle including rinse, backwash, and drains, h.

The numerator of the second term on the right side of equation 4 is the fresh regenerant volume from equation 1.

Equation 4 illustrates how t_c decreases as flow rate of exhaustion or regeneration are increased. However, an increased flow rate also can decrease q_{Ca} because of mass-transfer rate limitations which leads to decreased V_e per cycle. Thus, to compare various IX cycles in terms of the resin requirements for a plant design, a new combined variable is introduced.

The *time-weighted resin capacity* W for calcium removal is defined by:

$$W = \frac{q_{Ca}}{t_c} \qquad (5)$$

The units of W are equivalents of calcium per cubic meter of resin per unit of time. Use of subscript Ca with W is not used for brevity as with q_{Ca} but W always implies absorption of calcium in this report. Note that W is inversely proportional to V_{resin} according to equation 3.

There are practical hydraulic limitations which need to be considered in increasing flow rates. For example, a lower range of G_e may be accomplished by gravity flow through the resin bed but higher G_e would require an applied pressure to the top of the bed requiring a pressure vessel and greater pumping costs [16]. Thus, comparisons of IX performances among various cycles using their values of W alone are useful only within certain ranges of flow rates.

YDTF Results

The IX experiments at LVS were done after the similar series of experiments at the Bureau's YDTF in chronology and experimental design. Many of the findings from the YDTF were applied to the LVS experiments. A summary report [17] and a comprehensive final report [18] contain the data and analysis of the YDTF IX study. A summary of key YDTF results important to the LVS experiments are summarized here.

1. IX cycles having the steps listed in table 2B were the most successful in maximizing W while controlling any accumulation of gypsum scale in the resin bed. Thus, the use of a fluidized bed in regenerating the resin upflow and the use of recycled regenerant were confirmed.

2. Temperature was found to be a critical variable in determining the rate of formation of gypsum in the resin bed during regeneration. Higher temperatures caused faster rates of gypsum formation in the bed. Relatively low regeneration flow rates were insufficient to fluidize the bed adequately and lower the residence time of supersaturated regenerant solution for avoiding scale accumulation as described in 1. above.

3. There was insignificant correlation between the intensity of the gypsum scaling observed in the resin bed and IX performance in terms of softening. Permanent harm to the resin from the scaling was not observed. Accumulation of scale was removed from the resin bed by dissolution in a sodium chloride solution. The importance of gypsum scaling involved the need to maintain uniform flow distribution in the resin bed and to avoid flow blockage in the regenerant effluent piping. Accumulation of scale did not occur where the regenerant effluent and exhaustion influent piping were common because the feed water would redissolve any gypsum crystallites formed in the bed and common piping during the previous regeneration.

4. The addition of 100 g/m³ of SHMP (sodium hexametaphosphate) to the regenerant completely eliminated gypsum formation in the system. However, the addition of SHMP to the regenerants in a future IX plant at Yuma, Arizona, is not recommended because higher resin capacities occurred during cycles without SHMP and the addition of SHMP would be a multimillion dollar annual cost which is infeasible.

5. Microbiological growth occurred in the IX product water as a result of an absence of any disinfection following the IX. As a result, there were consistently high plugging-factor readings in the desalting feed water which would probably cause membrane fouling and loss in desalting performance as observed in the electrodialysis unit operated following the IX.

6. There was no observed advantage in using macroreticular cation-exchange resin in the IX experiments at the YDTF compared to what would be expected with the cheaper and slightly higher capactiy gel-type resin. Although the gel type was not tested at the YDTF, it had been successfully tested in similar applications elsewhere [10,11,15].

LA VERKIN SPRINGS FIELD EXPERIMENTS

Introduction

Ion exchange experiments were one of the most important aspects of field testing at La Verkin Springs. Other pilot plant equipment tested at LVS included aeration diffusers to remove carbon dioxide gas from the raw well water, a lime-softening-filtration system, a spiractor for desupersaturating calcium sulfate, and a reverse osmosis unit. Reports by the site contractor [5] and by the Bureau of Reclamation [6] describe the equipment for each test and contain the raw data. However, neither report contains an adequate analysis of the IX data nor presents conclusions. An analysis of the ED (electrodialysis) unit performance used for making the reject brine for IX regeneration is in another report [7].

Equipment

The IX equipment was described in detail (including photos and drawings) in a report of the IX experiments at the YDTF where the equipment was first operated [18]. The equipment was moved to LVS and modified slightly as described below. The test site is shown on figure 1. A flow sheet of the IX-ED system is shown on figure 2.

The IX pilot plant contained two transparent acrylic columns, 2.5 meters high and 0.34 meter inside diameter, each charged with about 1.15 cubic meters of DOWEX® HCR-W2 gel-type cation exchange resin. Manufacturer's specifications for

Figure 1. – View of the Laverkin Springs test site.

the resin are in appendix A. Much of the IX was controlled by a microprocessor operating about 35 electric motor-operated valves and 4 pumps. Figure 2 shows the various tanks used to store the various solutions including tanks 5 and 6 used to recycle regenerant.

At LVS, there were four changes made to the IX pilot plant equipment based on previous results at the YDTF described in the previous section of this report:

1. The Amberlite® 200 macroreticular cation exchange resin used at the YDTF was replaced at LVS with DOWEX® HCR-W2 gel-type cation-exchange resin. The gel-type resin was selected for LVS because:

a. The higher physical strength of the macroreticular type is unnecessary in the present process application.

b. The availability of the gel type is greater and its cost is lower.

c. The specific capacity of the gel type is about 10 percent greater.

d. The gel type has a smoother bead surface presumably allowing less adhesion of gypsum when formed during regeneration. It would be possible that gypsum could precipitate inside the pores of the macroreticular type, except for the fact that the pores are so small that the high negative charge density of the cation-exchange material probably excludes to a large extent the sulfate (divalent anion) from the resin-bead pores by electrostatic repulsion [19].

2. A heat exchanger was added to allow heating the IX regenerant to the maximum expected summertime water temperature of about 25 °C. The purpose of heating the regenerant was to simulant the worst operational condition of gypsum precipitation where the gypsum precipitation was at its

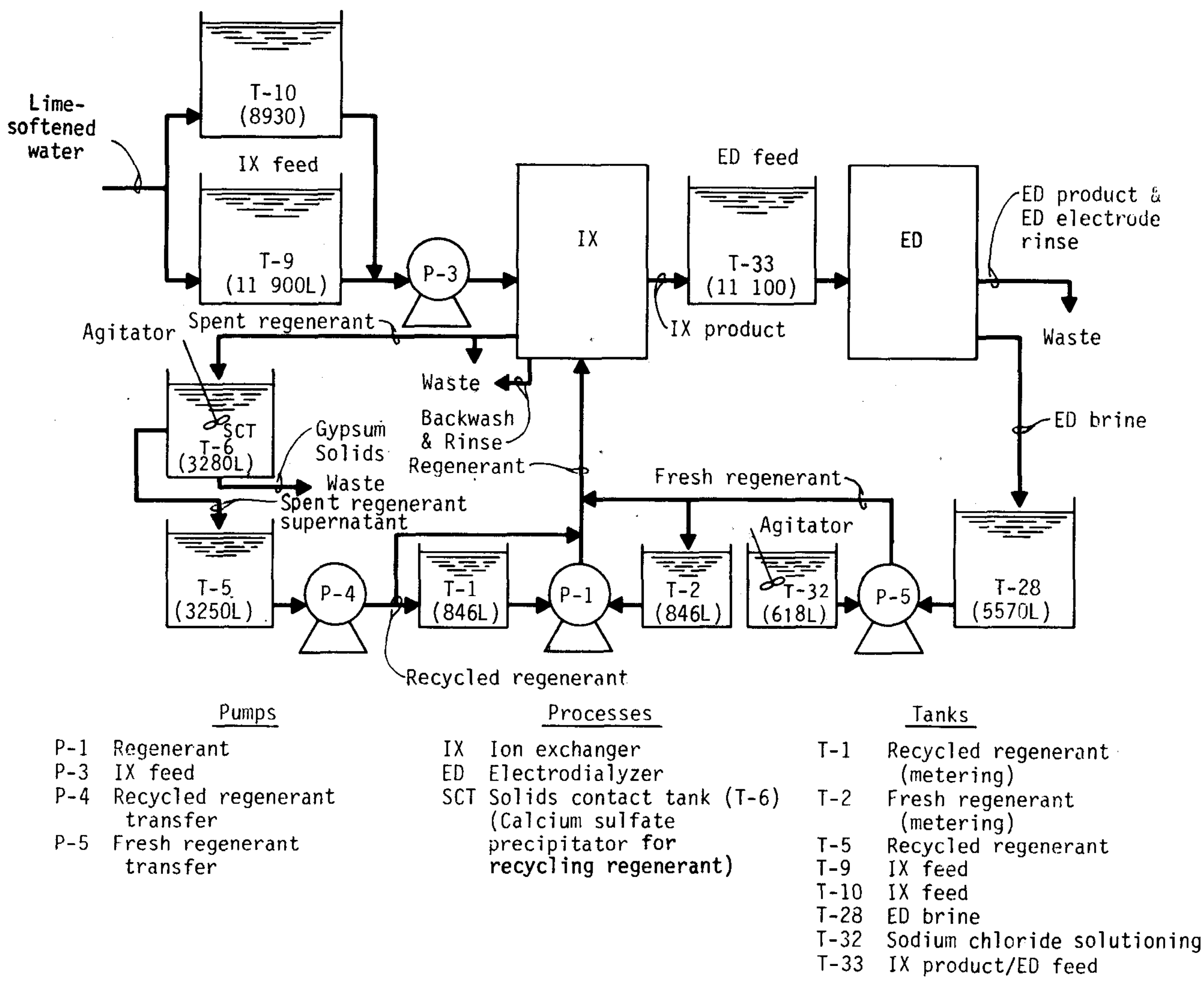

Figure 2. – Flow schematic of La Verkin Springs IX pilot plant.

maximum rate expected at LVS. The shell-side heating fluid for the heat exchanger was excess raw well water, which had a temperature averaging about 40 °C.

3. A system was installed in the IX column of the pilot plant for maintaining a packed resin bed during high upflow regeneration flow rates [20,21]. The system used a regeneration-effluent collector consisting of a cross of perforated pipe wrapped with No. 53 mesh-plastic screen, which is small enough to exclude resin particles larger than about 0.28 mm in diameter. As listed in appendix A, the HCR-W2 resin used was 99 percent larger than U.S.A. Standard sieve No. 40 (mesh) or greater than 0.42 mm in diameter. This collector was installed about 50 millimeters below the top of the settled resin bed.

Operation of the packed bed system involving the transition between Regeneration 1 and Regeneration 2 in table 2B is illustrated by the four steps on figure 3:

A. After completion of a usual Regeneration 1, which is a 10-minute backwash with recycled regenerant,

B. The upward flow through the column was stopped, the resin was allowed to settle, and the solution in the column was drained to the level of the collector. This left about a 50-mm depth of resin at the top of the bed in contact with moist air rather than being submerged in solution.

C. Just prior to Regeneration 2, a small flow of compressed air causing 50 to 100 kPa of pressure in the column was applied to the top of the column and the air allowed to exit the column through the midcolumn collector.

D. When Regeneration 2 was started, this downward airflow was sufficient to cause the upward flowing regenerant to leave through the midcolumn collector with the air and to maintain a packed bed. With the packed bed system, the maximum upward regenerant flows were 50 percent greater — limited only by the capacity of the regeneration pump — than the flow rates that were normally used for regeneration with a fluidized bed expanded by 50 percent.

4. An additional secondary chlorination system was installed to control microbiological growth in the IX product water piping and storage tank. The system added sodium hypochlorite solution to maintain a chlorine residual of 0.5 g/m³ in the IX product water. A dechlorination system was installed to add sodium sulfite to water leaving the IX product tank. The free chlorine residual was removed prior to the ED to prevent chlorine attack of the ED membranes.

Experimental Procedures

Pilot-plant operators (on duty 24 hours per day) measured and adjusted flow rates, measured tank

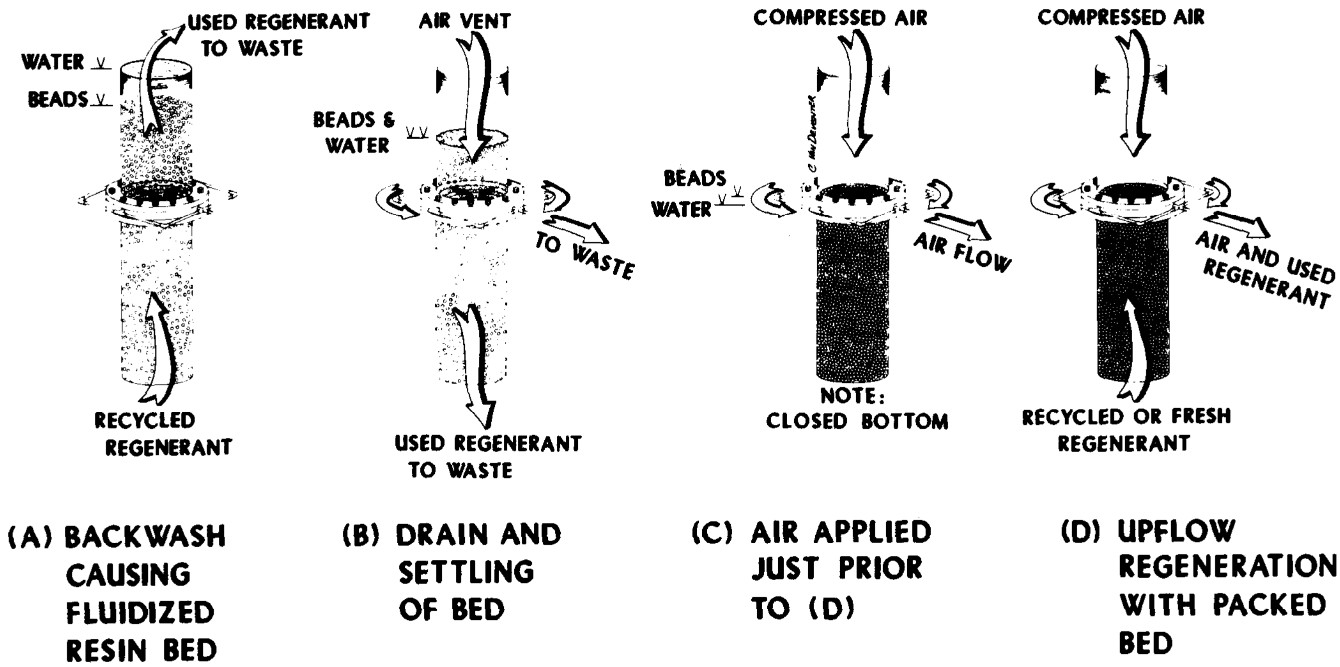

Figure 3. - Operation of packed bed system during regeneration.

volumes, and titrated samples of the IX exhaustion effluent for determining calcium breakthrough of the resin bed to terminate exhaustion. They made other readings and measurements, collected samples for the laboratory chemical analyses, and recorded observations. Chemical analyses of sodium, calcium, and magnesium were by atomic absorption spectrophotometry. More detail on measurement and calculation methods were published previously [18].

Desalting recovery was related to reject-brine TDS concentration by:

$$R = \frac{C'_f - C'_e}{C'_f - C'_p} \tag{6}$$

where:

R = the desalting recovery percent,
C'_f = TDS concentration of reject brine g/m^3,
C'_e = TDS concentration of desalting feed g/m^3, and
C'_p = TDS concentration of desalting product g/m^3.

Equation 6 was derived from a TDS mass balance about the ED unit. R was calculated using equation 6 because chemical analysis data was subject to less error than flow measurements. Two levels of reject-brine TDS concentration C'_f operated at LVS were about 42 and 97 kg/m^3, which correspond to desalting recoveries of 80 and 92 percent, respectively.

A trial and error approach was necessary to obtain the balance of feed and regenerant-brine flows dictated by equation 1. The process was judged at equilibrium after at least three repetitive cycles when the actual fresh regenerant volume and the volume calculated using equation 1 agreed within 10 percent. Unfortunately, because the LVS operating personnel did not accurately determine the brine TDS concentration during operation of the IX experiments, they presumed from ED operating data that the ED recovery was 90 percent at the higher level rather than the 92 percent that was later calculated from the laboratory TDS data. As a result, the fresh regenerant volume used per cycle at the higher brine concentration was about 20 percent too high. However, the recovery at 80 percent was correctly estimated in the field, and the regenerant volume and exhaustion volume balanced according to equation 1 at 80 percent recovery.

Experimental Design

The IX experimental design at LVS was in the nature of screening experiments [22]. The independent or control variables were controlled at just two levels in nearly every case. Dependent or response variables were measured at each set of control variables. Sufficient time was not available to experiment with intermediate control levels to generate response surfaces with equations higher than first order and therefore establish curvature between the control and response variables. Because the IX data were collected for feasibility and not design purposes, the amount of IX data collected at LVS by this experimental design was more than sufficient.

Dependent variables. – Dependent variables are also called the response variables. They are:

Specific resin capacity for calcium removal q_{Ca},
Time-weighted resin capacity W,
Intensity of gypsum scale in the resin bed, and
Calcium-sulfate supersaturation in the regeneration effluent.

The values of q_{Ca} were calculated using equation 2 with the integration done numerically using the trapezoidal method. Equation 5 defines W. Operating personnel qualitatively observed and recorded the intensity of gypsum scaling within the transparent IX column. An estimate of the amount of calcium-sulfate supersaturation in the regenerant effluent was calculated using a computer program listed in appendix C, modified from one developed by Marshall and Slusher [23].

Independent variables. – Independent variables are also called the control variables. In the field experiments they were:

Fresh regenerant TDS concentration C'_f g/m^3,
Fresh regenerant flow rate G_f m^3/s,
Recycled regenerant flow rate G_r m^3/s,
Recycled regenerant volume V_r m^3,
Regenerant temperature T_f degrees Celcius,
Fluidized versus compacted resin bed during regeneration,
Addition of SHMP to the regenerants, and
Special rinse procedures.

The regenerant brine TDS concentration was used to to determine other variables. Desalting reco[illegible] was related to C_f by equation 6. As discusse[illegible] viously, equation 1 fixed the volume of fresh re[illegible] ant to be used per cycle. The calcium break[illegible] concentration allowed before terminatio[illegible] exhaustion step was varied as a func[illegible] regenerant-brine concentration to more rea[illegible] reflect the different calcium-removal requi[illegible] for preventing calcium-sulfate precipitation [illegible] ent brine-concentration factors. Calcula[illegible] calcium-sulfate-saturation concentrations [LVS reject-brine compositions yielded 6 eq/ 12 eq/m^3 of calcium for desalting recoveries and 92 percent, respectively. Thus, calcium-concentration set points of 6 eq/m³ and 12 eq/m³ in the exhaustion effluent were used by the operators to terminate the exhaustion step during cycles with fresh regenerant TDS concentrations of 42 and 97 kg/m³, respectively. These set-point concentrations were conservatively low because the average calcium concentration of the exhaustion effluent was always much lower than the breakthrough concentration. This means that more feed water could have been passed through the resin during each exhaustion step, which would have yielded higher q_{Ca}, while still avoiding any gypsum precipitation in the ED.

Regenerant temperature was either ambient or raised to about 25 °C by a heat exchanger. The method for maintaining a compacted resin bed during upflow regeneration is described in the equipment section; otherwise the bed was fluidized. The SHMP addition to the fresh regenerant was at levels of zero, or at 100 g/m³ which is probably impractically high.

Special rinse procedures sometimes replaced the standard rinse in table 2 following regeneration with a compacted resin bed. The purpose of the special rinses was to try to alleviate some of the gypsum-scale accumulation in the resin bed and regeneration-effluent piping. Special Rinse 1 was an upflow rinse having a fluidized bed followed by a downflow rinse. Special Rinse 2 had three parts: a 1-minute downflow rinse, a 10-minute simultaneous upflow and downflow rinse exiting through the mid-column collector, and a final 1-minute downflow rinse.

Results

Table 3 summarizes the experimental pilot-plant data for the 16 IX data cycles completed in the experimental design at LVS. Figure 4 graphically shows the responses of the dependent variables q_{Ca} and W from table 3. Comprehensive sets of raw and calculated data for each of the data cycles is in appendix B. The cycle designations refer to, in order, L for La Verkin Springs, the IX run number operated at a given set of operating conditions, and the number of cycles completed at that operating condition culminating in the data collection cycle. Gaps in the numerical run number sequence occur because not all of the originally planned run conditions were started or completed with a full set of data because of the findings from preceding experiments or a limit of time. Note that the total number of cycles operated at the 16 operating conditions add up to 432, a relatively large number, which is why the experiments took some 3 months of continual operation to complete and were many times more expensive than the laboratory IX experiments.

Some of the chemical analysis results in appendix B are apparently in error. Indications of analytical error are that the equivalents per liter of anions and cations reported in some of the water samples do not balance as closely as the expected precision of the analytical methods and that the total normalities of the solutions flowing into and out of the IX resin bed are not always nearly equal when they must be (unless at the beginning of a step another solution from a preceding IX step had not yet been displaced). The errors are most apparent in the compositions of the regenerants, which required extreme dilution prior to analysis by atomic absorption spectroscopy because of their high ionic concentrations, that were done by the E&R Center chemistry laboratory. Many of the samples were rerun at the E&R Center; still, a few of them seem to be in error. Generally, the analyses done by the Bureau's Boulder City, Nevada, regional laboratory and the laboratory at the YDTF do not have such inconsistencies. Fortunately, the exhaustion samples, used to calculate the resin capacities, seem to be reasonably accurate. The results presented and discussed in this report are thought to be based on accurate chemical analyses, unless otherwise explicitly indicated.

The amount of gypsum scaling in the resin bed, another interesting response variable, was not directly quantifiable. Qualitative gypsum scaling observed in the resin bed are noted in the following paragraphs analyzing the response to each control variable. In addition, calculated calcium-sulfate supersaturation levels in some of the regeneration-effluent solutions is in table 4. Values in table 4 represent the amounts of calcium sulfate that would precipitate from the supersaturated regenerant-effluent solution if allowed to come to equilibrium at 25 °C. The complete computer printouts of the results and the computer program used to calculate these supersaturation values are listed in appendixes C and D.

Regeneration TDS concentration. – As shown on figure 4, both q_{Ca} and W were higher with $C'_f =$ 92 g/L (92 percent recovery reject brine) than they were with $C'_f =$ 40 g/L (80 percent recovery reject brine). For the last 11 runs of the 12, with $C'_f =$ 92 g/L excluding run number 5, it is remarkable q_{Ca} was so invariant, relatively (mean of 1.032 eq/L and standard deviation of 0.046 eq/L). With $C'_f =$ 40 g/L, no gypsum scale accumulated in the resin bed when recycled regenerant was used preceding fresh regenerant, which agrees with results at the YDTF [18]. Note also that the amount of supersaturation in the regeneration effluent was also relatively lower under these conditions (cycle L.02.12 in table 4). But with $C'_f =$ 92 g/L, gypsum scale remained in the IX column at the end of regeneration with all operating conditions except when

Table 3. – *Results of La Verkin Springs ion exchange experiments*

Cycle designation	Notes	1980 Date run	Fresh regen. TDS conc. g/L	Fresh regen. flow rate L/min	Recycled regen. flow rate L/min	Recycled regen. volume L	Fresh regen. temp. °C	Calcium specific resin capacity eq/L	Exhaustion duration min	Cycle duration min	Exhaustion fraction of cycle time	Time-weighted resin capacity meq/L min
80 percent recovery reject brine regeneration. Exhaustion termination concentration 12 meq/L of calcium												
L.01.97		1-29	41.3	12.1	NA	0	15.5	0.585	120	216	0.559	2.71
L.02.12	H	2-1	39.8	12.1	24.0	1591	11.8	0.761	152	317	.480	2.40
L.03.35	PH	2-14	39.4	11.9	NA	0	25.9	0.681	153	253	.599	2.69
L.04.11	PH	2-17	39.8	12.0	24.2	1573	25.5	0.860	189	370	.510	2.32
92 percent recovery reject brine regeneration. Exhaustion termination concentration 6 meq/L of calcium												
L.05.54	H	2-28	92.0	26.0	NA	0	26.8	0.341	73	118	.619	2.89
L.10.14	H	3-8	93.4	23.6	23.1	1594	26.4	1.019	187	308	.609	3.31
L.12.22	PH	3-14	92.8	23.7	23.8	1610	25.0	0.996	201	318	.631	3.13
L.17.17	PH	3-18	93.3	33.6	32.2	1602	25.7	1.082	196	296	.662	3.66
L.18.13	P	3-21	91.3	23.6	24.1	1592	17.6	1.089	196	321	.610	3.39
L.19.27	P	3-27	90.8	36.3	34.7	1597	13.6	1.012	188	283	.660	3.58
L.20.09		3-29	91.9	23.7	23.6	1603	13.6	1.065	198	316	.630	3.37
L.22.15	P	4-4	90.9	35.8	33.0	793	17.5	0.991	178	250	.710	3.96
L.23.19	PS	4-16	90.0	24.0	NA	0	22.5	0.964	177	228	.780	4.23
L.24.11	PHS	4-18	90.1	23.2	NA	0	29.5	1.030	191	243	.786	4.24
L.25.22	PR1	4-9	92.8	30.6	33.1	791	19.4	0.998	193	282	.680	3.54
L.26.14	PR2	4-12	92.8	33.0	33.1	798	19.4	1.103	200	278	.750	3.97

Notes:
H – heat exchanger used to heat regenerant to summertime temperatures.
P – resin bed packed during upflow regeneration. In other cycles the resin bed was fluidized during regeneration.
S – SHMP (sodium hexametaphosphate) added to regenerant to prevent gypsum scaling.
R1 – special upflow rinse followed by a downflow rinse.
R2 – simultanteous upflow and downflow rinses passing out of the column through the collector in top of the resin bed.
NA – not applicable.

SHMP was added to the fresh regenerant (see paragraph following regarding SHMP added). This agrees with data in table 4, which shows the greatest levels of supersaturation for cycles L.05.54 and later having $C'_f = 92$ g/L of TDS.

Use of recycled regenerant. – The use of recycled regenerant increased q_{Ca} and moderated gypsum scaling. During run number 5 when recycled regenerant was not used ($V_r = 0$) and $C'_f = 92$ g/L, gypsum scaling was so severe that flow distribution in the resin bed was hampered greatly and the gypsum redissolved during rinse and exhaustion, which apparently contributed to the lower q_{Ca}. The high level of gypsum scaling of run 5 agrees with the high level of supersaturation for L.05.54 in table 4. Decreasing V_r from 1600 to 800 L without SHMP and to zero with SHMP had no significant affect on q_{Ca}, but decreasing V_r did increase W as would be expected from equations 4 and 5.

Packed bed and regeneration flow rate. – The maximum regeneration flow rates (G_f for fresh regenerant and G_r for recycled regenerant) that were possible with a fluidized bed having 50 percent bed expansion were about 24 L/min at the lowest regenerant temperatures because the fluidized bed reached the top of the column at these conditions. Because there was not this limitation when a packed bed was maintained, the regeneration flow rates could be increased to 36 L/min, the upper limit for the flow

Table 4. – *Calculated calcium-sulfate supersaturation in regenerant effluent of selected LVS IX cycles. Each regeneration-effluent stream listed had the highest level of supersaturation in that respective IX cycle. Calculation procedure modified from methods developed by Marshall and Slusher [23] were detailed previously in the final Yuma high recovery report. [18]*

Cycle number	Effluent stream	Calcium-sulfate Supersaturation (millimoles/L)* average	peak
L.02.12	Regeneration 1/2	8.8	25.9
L.03.35	Regeneration 3	34.8	50.5
L.05.54	Regeneration 3	70.4	100
L.10.14	Regeneration 2	29.7	70.6
L.22.15	Regeneration 2	40.1	74.0
L.23.10	Regeneration 3	83.2	150
L.24.11	Regeneration 3	73.1	143
L.26.14	Regeneration 2	45.7	84.0

* Predicted amount of calcium sulfate that would be precipitated at 25 °C if allowed to come to chemical equilibrium based on chemical analyses of supersatured regenerant-effluent solutions given in appendix B.

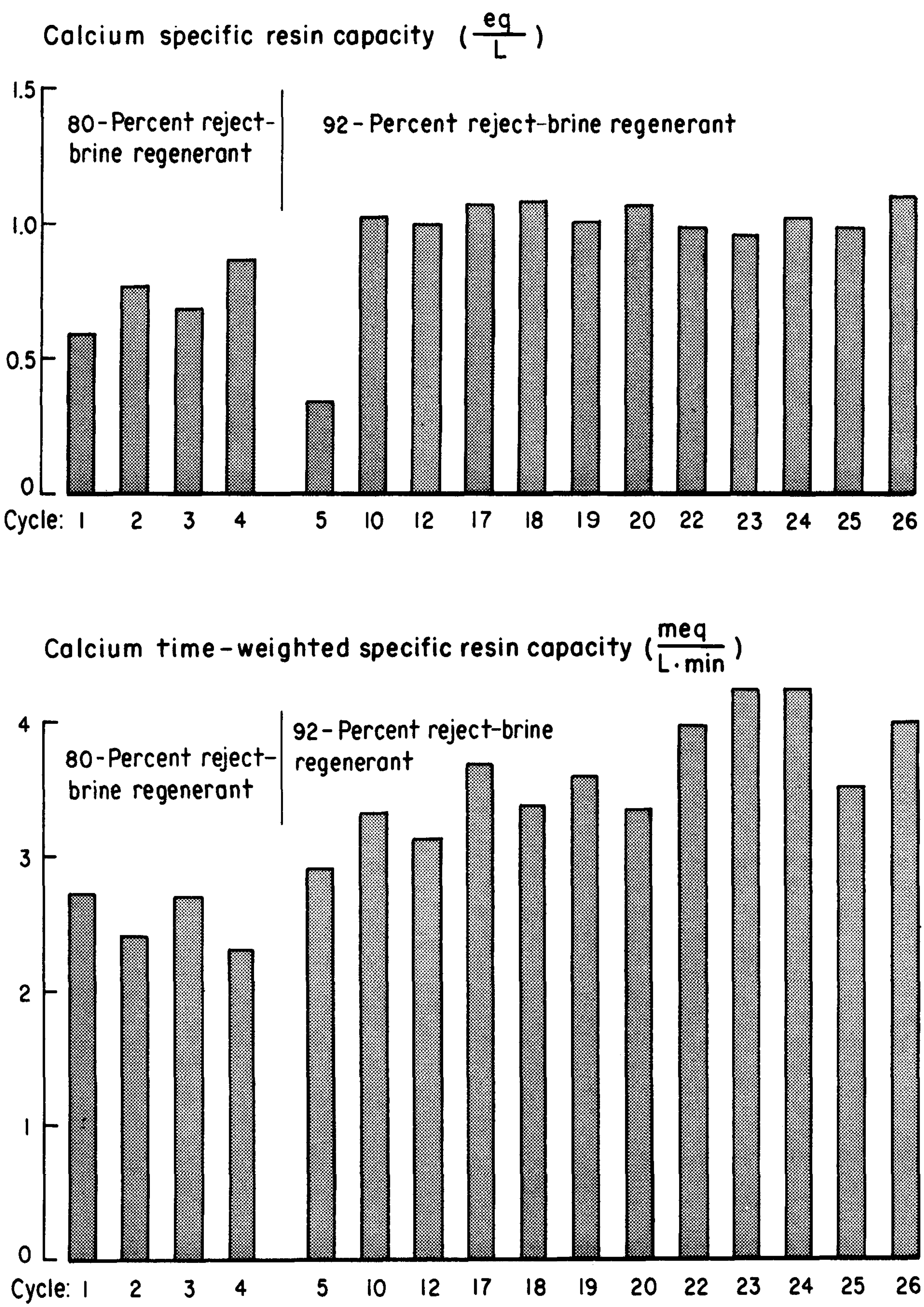

Figure 4. – Specific calcium resin capacities and time-weighted resin capacities during LVS field experiments.

capacity of the regenerant pump used. Qualitatively, there was less gypsum scale formed and accumulated in the resin bed at $C'_f = 92$ g/L when a packed bed was used than when the bed was fluidized during regeneration. This contrasts with the result that the average amount of calcium-supersaturation apparently was somewhat greater with the packed bed (cycles L.22.15 and L.26.14 in table 4) than with a fluidized bed (L.10.14). However, during packed bed regeneration, gypsum scale accumulated gradually in the midcolumn collector system used to maintain the packed bed, which blocked regenerant flow. The obstruction of flow could only be eliminated by suspending operation while operators scraped the gypsum scale from the collector and, in the most severe cases, had to replace the piping because they were unable to remove the gypsum scale. Yet, there was no significant difference in q_{Ca} whether or not a packed bed was used. The use of a packed bed and a higher regeneration flow rate did increase W, largely because the cycle time was less according to equation 4.

Regenerant temperature. – No consistent difference in q_{Ca} or W occurred among the runs whether or not the heat exchanger heated the regenerant by up to 15 °C. The gypsum scaling in the IX column was worse qualitatively at higher temperatures, which agrees with results at the YDTF. There was no apparent effect of temperature on the amount of calcium-sulfate supersaturation.

SHMP added to the fresh regenerant. – No gypsum accumulated in the IX system during the addition of 100 g/m³ of SHMP (sodium hexametaphosphate) scale inhibitor to the fresh regenerant and with a packed bed, even when $C'_f = 92$ g/L and with no recycled regenerant, which create serious gypsum scaling without SHMP. Yet the amount of supersaturation in the regeneration effluent was greatest when SHMP was used (cycles L.23.10 and L.24.11 in table 4), apparently because no recycled regenerant was used at the time of SHMP addition. The use of SHMP did not increase q_{Ca} despite the absence of gypsum-scale formation, but W increased because recycled regenerant was not used, which lowered t_c by eliminating the third term of cycle time in the right side of equation 3.

Alternative rinse procedures. – The special Rinse 1 had no beneficial effect on moderating gypsum scaling in the resin bed. However, special Rinse 2 was successful in reducing visible gypsum scale in the resin bed, but there was still some scale buildup in the effluent collector piping.

Gel-type resin. – Only macroreticular resin was operated at the YDTF, and only the gel type was tested at LVS. Thus no quantitive comparisons between performances of the two types of cation-exchange resin are possible. However, it was found qualitatively that gypsum scale, when formed, was shed more easily from the surfaces of the gel-type resin than was observed with the macroreticular resin at the YDTF. With the gel resin at LVS, any gypsum in the resin bed acted like a separate slurry phase that did not stick to the resin beads but could be backwashed from the column.

Chlorination of the IX product water. – High plugging factors did not occur in the IX product water at LVS as they did at the YDTF. At LVS, chlorination of the IX product apparently controlled microbiological growth and kept plugging factors low. Operation without chlorine in the IX product was not attempted at LVS.

Discussion

The relative constancy of the specific calcium resin capacity q_{Ca} at about 1.0 eq/L when the fresh regenerant TDS, $C'_f = 92$ g/L, at a variety of operating conditions suggests that the resin was nearly at equilibrium with the fresh regenerant solution following regeneration during these cycles. This is verified by results from an equilibrium model in a later chapter on modeling. The maximum or total specific resin capacity of DOWEX®HCR-W2 in the sodium form is given in appendix A as 2.0 eq/L. The value of 1.0 achieved at LVS is nearly double the maximum value that was obtained at the YDTF, which cannot be accounted for in the 10-percent higher total capacity of the gel resin operated at LVS relative to the total capacity of the macroreticular resin used at the YDTF. But many other variables were different between the two sites, particularly the water compositions. A mass balance of sodium between the fresh regenerant and resin bed of the pilot plant per cycle at LVS shows that the equivalents of sodium in the fresh regenerant volume when $C'_f = 92$ g/L was over five times the calcium resin capacity of the bed. It is also possible to conclude that the recycled regenerant had no significant benefit in increasing q_{Ca} in terms of IX equilibria and stoichiometry.

Gypsum scale in the resin bed. – The recycled regenerant was beneficial, however, in limiting the detrimental effects of gypsum scale. Because the recycled regenerant is relatively weaker in strength (lower in sodium and TDS and higher in calcium) than the fresh regenerant, the recycled regenerant elutes calcium from the exhausted resin bed in lower concentrations. The recycled regenerant also contains relatively less sulfate than the fresh regenerant. The relatively lower calcium and sulfate concentrations create a lower level of calcium-sulfate supersaturation in the recycled regenerant effluent compared to the effluent from fresh regenerant that is not preceeded by recycled regenerant.

The calculation of the amount of calcium-sulfate supersaturation in the regeneration effluent appears to correlate well with observations of gypsum scaling based on results at LVS and previous results from the YDTF [18]. The supersaturation values in table 4 tend to agree with the qualitative observations of gypsum scaling. Serious gypsum-scale accumulation in the IX system was largely avoided in the present pilot plant at temperatures up to about 30 °C when the average calcium-sulfate supersaturation level in the regeneration effluent was less than approximately 40 millimoles per liter, the residence time in the resin bed was less than about 4 minutes, and recycled regenerant was used preceding fresh regenerant. Gypsum-scale formation was avoided with higher levels of supersaturation when the regenerant temperature was below 20 °C, which was shown to lower the kinetic rate of gypsum formation at the YDTF, and when SHMP was present to inhibit gypsum formation.

The kinetics of gypsum formation are described by an equation from experimental work [14] on the rate of precipitation of gypsum from a supersaturated calcium-sulfate solution in the presence of gypsum seed crystals:

$$-\frac{dN}{dt} = knN^2 e^{-E/RT} \tag{7}$$

where:

$-\frac{dN}{dt}$ = rate of loss of supersaturated calcium sulfate,
= - rate of gypsum-precipitate formation,
k = reaction rate constant,
n = number of gypsum seed crystals per volume,
N = number of moles per liter of calcium sulfate that will precipitate before equilibrium is reached,
E = activation energy for the reaction,
R = universal gas law constant, and
T = absolute temperature.

Note that N corresponds to the levels of calcium-sulfate supersaturation (times 10^{-3}) in table 4.

Equation 7 expresses that the level of calcium-sulfate supersaturation in the regeneration effluent will largely determine quantitatively not only the potential amount but the rate of formation of gypsum in the IX system. The initial rate of formation of gypsum from a supersaturated solution with gypsum seed crystals present is proportional to the level of supersaturation to the 2d power according to equation 7. Thus, a doubling of the supersaturation levels in table 4, as between experimental cycles, means a four-fold increase in the rate of gypsum formation. By using equation 7, it seems entirely feasible that the regeneration-effluent calcium-sulfate supersaturation levels, which can be predicted from actual or projected regeneration-effluent compositions using the computer program listed in appendix C, could be used to predict whether gypsum scale will accumulate in an IX system operated with a given regenerant residence time. Note, however, that the concentration of initial gypsum crystallites was not measured. A relatively low n causes an "induction" period where crystallites are formed from the supersaturated solution. Thus, the results of such predictions would need experimental verification.

The success of the packed bed during regeneration when gypsum is precipitating in the resin bed is a new concept established in the present work at La Verkin Springs. All previous work described in the literature, including even the YDTF experiments, concluded — or assumed since a packed bed was not tested in any of these studies — that a fluidized bed is necessary to expel precipitating gypsum in the regenerant from the resin bed.

Much of the success of a packed bed in the present experiments is attributed to the much lower residence time of the regenerant solution in a packed resin bed, which allows more of the supersaturated calcium sulfate to be more quickly removed from the bed before gypsum can precipitate. In the present pilot plant, where the settled resin bed had a volume of 115 L and an assumed void-volume fraction of 0.3, the packed resin bed had a void volume of (0.3) (115) = 34.5 liters. But the bed fluidized by 50 percent had a void volume of (0.3) (115) + (0.5)(115) = 92 liters. The maximum flow rate possible with the 50-percent fluidized bed was about 24 L/min, but a maximum of 36 L/min was attained with the packed bed. Thus, the minimum regenerant residence time was 92 L ÷ 24 L/min = 3.8 minutes for the fluidized bed, but only 34.5 L ÷ 36 L/min = 0.96 minute for the packed bed. Therefore, assuming plug flow, operation with the packed bed allowed nearly four times less opportunity for gypsum to precipitate in the resin bed. The factor difference is probably greater than four because a greater deviation in plug flow occurs in the fluidized bed. Furthermore, despite its low void volume, the packed bed showed no more propensity than a fluidized bed to retain gypsum scale as had been feared by proponents of the fluidized bed regeneration. An additional benefit from the use of higher regenerant flow rates through a packed bed is an increased W, which lowers the flow capacity of the IX equipment required and, thus, the capital cost of a full-size IX plant.

The accumulation of gypsum scale in the midcolumn regeneration-effluent collector was troublesome during the experiments because it obstructed the flow, which required considerably extra maintenance. This problem would need to be solved prior to the use of reject-brine regeneration in a full-sized IX plant at LVS. There are two promising methods of solving the problem, neither has been tested:

1. A portion of the exhaustion feed water would be passed into the resin bed through the regeneration-effluent collector during the rinse and exhaustion steps. The feed water would redissolve any small amount of gypsum formed in the piping during the preceding regeneration. This rinsing method should be effective because in all IX testing at the YDTF and at LVS gypsum-scale accumulation was avoided where the regenerant effluent and the feed water passed alternately through the same section of piping. Experimental verification of this rinsing procedure applied also to the midcolumn collector of the packed bed is needed. The second special rinse method tested (or a variation of it) would also aid somewhat in preventing scale accumulation in the resin bed.

2. Using a weaker, more dilute recycled regenerant prior to the fresh regenerant is effective also. The recycled regenerant caused a lower level of calcium-sulfate supersaturation and less gypsum scaling in the regeneration effluent than did the fresh regenerant, which was attributed to the lower sodium concentration of the recycled regenerant. To meet the previously established objective of maximizing specific calcium resin capacity, the regenerant that was recycled during all the experiments was made to be as high in sodium concentration as possible by wasting the initial portion of the regeneration effluent. However, by collecting the initial regeneration effluent containing a portion of solution remaining from exhaustion and the initial regeneration effluent containing the lowest concentration of sodium, a weaker recycled regenerant would have been collected. In fact, nearly any strength of recycled regenerant (naturally, less strong than the fresh regenerant) would be possible by collecting and recycling selected fractions of the regeneration effluent. Thus, the initial level of calcium-sulfate supersaturation in the regeneration effluent could be lowered to a level to minimize gypsum-scale formation during regeneration by adjusting the strength (sodium content) of recycled regenerant using this approach. Once such methods were developed and established by experimentation, the procedures would be simple to execute routinely and be effective in a full-sized plant.

SHMP addition. – The question of whether SHMP should be used, in the regenerant to avoid all gypsum-scale formation in the resin bed, is an economic one. An economic analysis would involve a balance between operational costs of SHMP purchase and handling versus amortization of capital costs and operating costs of extra equipment including a regenerant recycling system to handle the precipitating gypsum. Even if dosages substantially less than 100 g/m³ of SHMP would be effective in preventing gypsum precipitation, the continual purchase of SHMP or an alternative precipitation inhibitor in a very large plant would be a multimillion-dollar annual cost — much greater than the cost of regenerant recycling. The quantitive effects of gypsum scale in the resin bed on the principle process parameters q_{Ca} and W were insignificant, except when the scaling was extremely severe, which occurred only when no recycled regenerant was used at the higher regenerant concentration. A relatively minor savings in capital cost would occur if the regenerant-recycling system was not provided and SHMP was used instead, which also would increase W by about 5 percent and, thus, decrease the total resin requirement by approximately 5 percent. Therefore, the use of SHMP should be — and can be — avoided with careful intelligent plant design, which should result in an overall lower water treatment cost. The IX-plant cost estimate was not in the scope of this present work.

LABORATORY ION-EXCHANGE EXPERIMENTS

Introduction

Obtaining IX feasibility data by pilot plant experiments in the field, as those described in the previous section at LVS, is quite expensive. As shown in table 2, numerous cycles were required to test at a single condition at the LVS site, largely because a balance between volumes of fresh regenerant and exhaustion (equation 1) required a trial and error approach and because a number of cycles were required after a control variable change to reach a new system equilibrium. Less expensive approaches are to use laboratory IX experiments and mathematical modeling of the IX process to predict IX performance at the actual site.

The major purpose of the laboratory IX experiments was to obtain IX feasibility data at different operating conditions on synthetic LVS water solutions, which would supplement data collected at the LVS site. The laboratory data was analyzed with regard to determining to what extent the laboratory experiments using synthetic waters could substitute for the much more expensive field pilot-plant experiments just described previously. This section contains the methodology of the laboratory experiments, the laboratory data, and comparisons of the laboratory results with the LVS field results.

A second purpose of the laboratory experiments was to provide data for developing, fitting, and testing mathematical models capable of predicting IX-pretreatment process performance as applied to LVS. The IX modeling and comparisons to IX data are in the following section entitled ION–EXCHANGE MODELS.

A requirement established for the IX laboratory experiments was that the experimental procedure would be simple and quick enough so that the IX performance for a set of process variables could be determined in 1 day by one or two technicians including the chemical analyses, which limited testing to one IX cycle. Thus, in the laboratory experiments, only one cycle per condition was usually operated, but the exhaustion and regeneration were done with sufficiently large volumes of solution to approach equilibrium between the solution and the entire bed of cation exchange resin. Unlike the field experiments, the exhaustion step was operated without regard for terminating exhaustion at some low calcium-breakthrough concentration, and the regenerant volume was not limited by equation 1. An approximate equilibrium condition between feed solution and resin was assumed when the composition of the effluent solution was about the same as the composition of the influent solution.

Another difference between the laboratory experiments and the field experiments was that the solutions made to simulate LVS water consisted of the chloride salts of calcium, magnesium, and sodium (except during the last cycle of the tests when sulfate salts were also added). By avoiding sulfate and not introducing the complications of gypsum precipitation during regeneration, the laboratory IX experiments concentrated on studying equilibrium effects between the resin and different solution compositions, the mass-transfer rates between the solutions and resin, and the dynamics of ion exchange in a fixed resin bed. Laboratory experiments, however, provided little additional information on the impacts of gypsum precipitation in the resin bed during regeneration.

Equipment and Procedures

The flow diagram of the laboratory IX equipment is shown on figure 5. The IX column consists of heat-resistant glass with Teflon™ and polypropylene end fittings is about 2 meters high and 25 millimeters inside diameter and is surrounded by a glass water jacket. The column contained 500 milliliters of DOWEX® HCR-W2, the same cation-exchange resin tested at LVS. The exhaustion and regeneration pumps are positive displacement roller tubing pumps having variable speed controls. Temperatures were maintained at set levels by a temperature-controlled water bath. As shown on figure 4, the influent exhaustion and regeneration solutions passed through stainless steel coils (made from discarded gas-chromatographic columns) to approach the temperature of the water bath. Recirculated water from the bath was pumped through the water jacket to control the resin bed temperature at close to water-bath temperature. Flow rates were monitored by rotameters and regularly confirmed by bucket-and-stopwatch measurements. Temperature measurements were by glass thermometers. The tanks were polyvinyl chloride. The exhaustion feed tank had a 208-L capacity and an agitator to mix the solutions. Each regeneration tank was 57-L capacity.

Data collection for the laboratory IX experiments was similar to that of the field experiments. Data sheets are in appendix E.

Depending upon the water compositions being run, regenerations required about 15 bed volumes (500 mL each in the present experiments) and the exhaustions approximately 100 bed volumes before the influent and effluent compositions were approximately equal. Deionized water was passed through the column between each regeneration and exhaustion step to rinse residual solution from the bed prior to the next step of the cycle. Calcium and total hardness were determined by EDTA (**E**thylene**d**iamine**t**etra**a**cetic acid) titration [24]. Magnesium concentration was calculated as the difference between the total hardness and calcium concentrations. Sodium was measured by flame emission photometry. As in the field experiments, the calcium and magnesium specific resin capacities were calculated using equation 2 in which the integration was performed numerically using the trapezoidal method.

Experimental Design

The dependent variables were the effluent concentrations of calcium, magnesium, and sodium versus effluent volume of exhaustion and regeneration. The specifiic resin capacity for calcium q_{Ca} and the same for magnesium q_{Mg} were determined from the effluent curves. The independent control variables — all operated at two levels each — included the following:

I. Exhaustion feed-water cationic composition:

   A. Aerated, lime-softened LVS water (F-1)

calcium:	22 meq/L
magnesium:	11 meq/L
sodium:	100 meq/L

B. Aerated LVS water (F-2)
calcium: 42 meq/L
magnesium: 11 meq/L
sodium: 100 meq/L

II. Regenerant cationic composition:

A. LVS desalting reject brine at 80-percent recovery (R-1)
calcium: 18.5 meq/L
magnesium: 23 meq/L
sodium: 574 meq/L

B. LVS desalting reject brine at 90-percent recovery (R-2)
calcium: 20 meq/L
magnesium: 40 meq/L
sodium: 1370 meq/L

III. Feed and regeneration water temperature:

A. 15 °C
B. 35 °C

IV. Exhaustion flow rate:

A. 5 mL/s (0.60 bed volumes per minute)
B. 11 mL/s (1.3 bed volumes per minute)

V. Regeneration flow rate:

A. 1 mL/s (0.12 bed volumes per minute)
B. 3 mL/s (0.36 bed volumes per minute)

The preceding control variables and their levels were selected for the following reasons:

1. The lime-softened feed water (F-1) approximated the water fed to the IX pilot plant operated at LVS. The composition of the aerated water (F-2) represented what would be expected if lime treatment were omitted prior to IX at LVS, which was not pilot tested at the LVS site. Pretreatment at LVS would probably be less expensive if lime treatment were not needed prior to IX, and it is not apparent why lime treatment would be needed other than perhaps for silica removal.

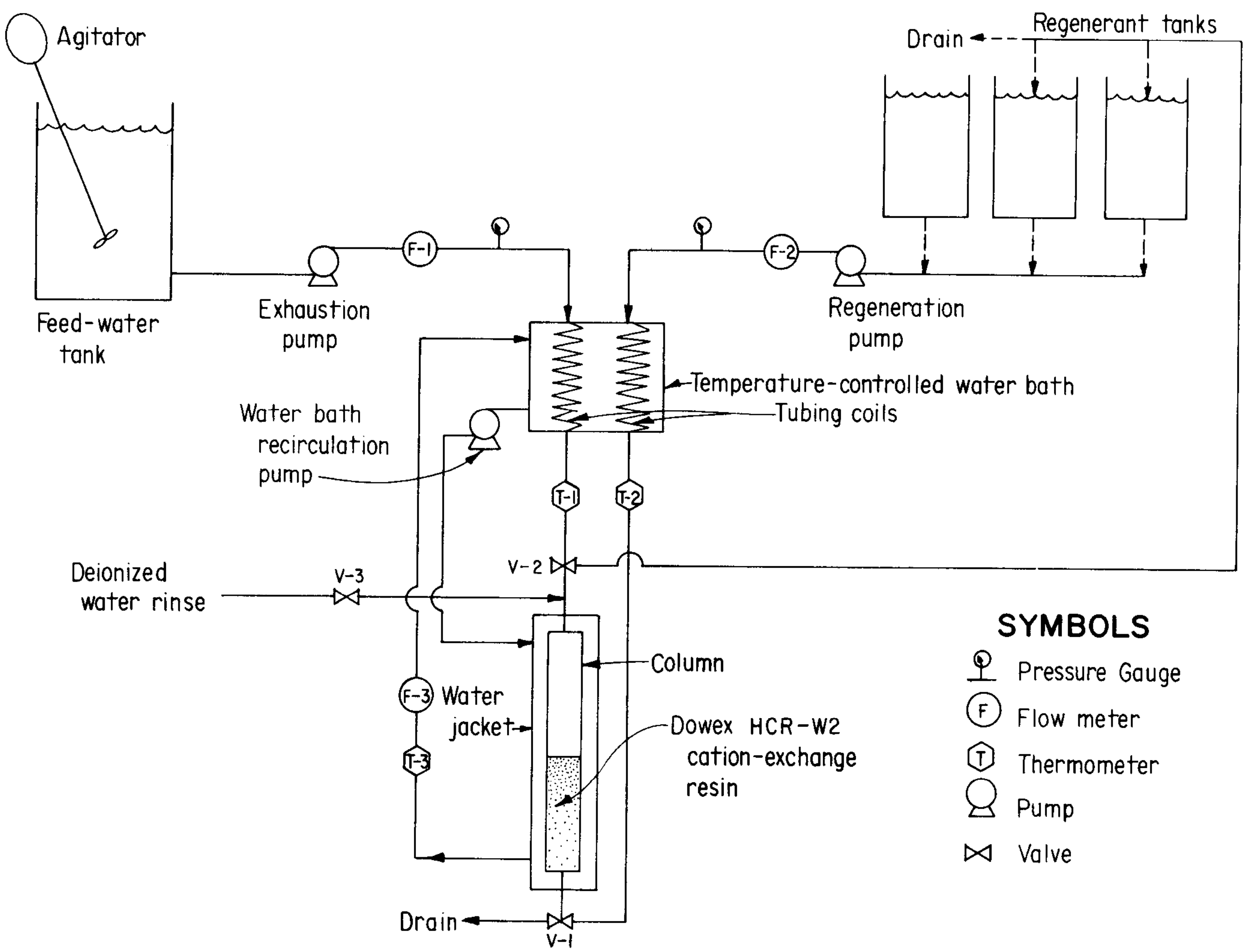

Figure 5. – Flow schematic of laboratory IX equipment.

2. The two regenerant compositions (R-1 and R-2) approximated the concentrations in the ED reject at the two ED desalting recoveries operated in the LVS field experiments. Thus, they represent fresh regenerant compositions only.

3. The two water temperatures represented ambient extremes normally expected at LVS. It was desired to find whether temperature would affect IX performance aside from its effect on rates of gypsum scale formation during regeneration as observed in the field experiments.

4. Exhaustion flow rate was varied to determine its effect on IX performance and to aid in modeling. Exhaustion flow rates in the laboratory experiments were considerably higher than the 0.26 bed volume per minute used in the field experiments. Unfortunately, there was no overlap in the ranges of exhaustion flow rates between the laboratory and field tests, which occurred because of a simple mistake in computing the laboratory flow rates to be used prior to conducting the laboratory experiments.

5. The effect on IX performance of varying regeneration flow rate was of interest. The field IX experiments used fresh regenerant flow rates of about 0.2 to 0.3 bed volume per minute which overlaps the range used in the laboratory experiments.

In developing the experimental design, different combinations of these control variables were selected randomly for each regeneration and independently for each exhaustion, except that exhaustion temperature was matched to regeneration temperature to avoid changing the temperature during a cycle so that the cycle could be completed in a single day. The completed experimental design, including the measured control-variable levels and their sequence, is in table 5. This type of design was used because it is economical (more information per experiment is possible) and it minimizes certain types of experimental bias; for example, if an uncontrolled variable affecting the response variable varied with the time of the experiment [22]. The experimental design allowed statistical and regression analysis of the IX response variables as a function of the five control variables. An additional run was added to the end of the design which included sulfates in the water composition to better simulate real conditions where calcium-sulfate supersaturation and gypsum scaling would occur.

Results and Discussion

For the exhaustion step of cycle 1.01.06, the effluent cationic concentrations of calcium, magnesium, and sodium versus bed volumes of resin-bed effluent solution are shown on figure 6. The behavior of effluent-concentration curves (fig. 6 as example) can be described as follows:

1. There are initial small leakages of calcium (about 0.2 meq/L) and magnesium (about 0.7 meq/L) at the beginning of exhaustion. This leakage occurs largely because the resin was regenerated with a mixture containing calcium and magnesium in addition to sodium, for if the regenerant contained only sodium cation the initial calcium and magnesium leakage would be negligible. Another reason for this leakage is hydrodynamics in the resin bed whereby some of the solution avoids intimate contact with the resin bed.

2. As exhaustion procedes, wherein the divalent cations exhaust the resin bed, the sodium concentration in the effluent increases and reaches a

Table 5. – *Measured laboratory control-variable levels*

Cycle number	Steps	Compositions*, meq/L Ca	Mg	Na	Flow mL/s	Temp. °C
1.01.01A	Exhaustion	21.8	11.8	89.6	11.5	17.0
1.01.01B	Regeneration	31.0	36.0	1420	3.1	14.7
	Exhaustion	24.3	22.7	108.5	11.8	14.9
1.01.02X	Regeneration	36.7	26.2	1400	0.98	34.0
	Exhaustion	22.7	0.5	93.3	11.1	34.0
1.01.02B	Regeneration	23.3	44.7	1340	1.02	35.0
	Exhaustion	42.0	9.3	101.3	11.2	34.0
1.01.03	Regeneration	24.0	44.0	1362	0.97	16.1
	Exhaustion	26.8	7.6	102	5.2	16.0
1.01.04	Regeneration	22.2	23.1	577	3.0	35.3
	Exhaustion	23.2	13.0	102	5.1	34.7
1.01.05	Regeneration	22.2	22.6	584	0.99	35.0
	Exhaustion	40.1	10.7	92.8	5.2	34.9
1.01.06	Regeneration	24.0	36.0	1428	3.0	33.2
	Exhaustion	23.4	12.2	102	11.0	33.2
1.01.07	Regeneration	22.4	21.7	486	0.99	16.0
	Exhaustion	41.6	11.6	80	11.0	17.0
1.01.08	Regeneration	18.0	22.8	643	3.02	15.0
	Exhaustion	40.2	11.2	93.5	4.95	14.5
1.01.08B	Regeneration	2.8	2.0	1800	1.03	22.0
1.02.01	Exhaustion	22.4	11.2	95	4.98	34.7
	Regeneration	22.4	25.4	587	2.97	15.0

* The anion in all of the solutions was chloride except in cycle 1.02.01 when the exhaustion feed water contained 2000 mg/L of sulfate and the regenerant contained 9000 mg/L of sulfate with the balance chloride. Because of problems in making the correct regeneration and exhaustion solution concentrations in cycle 1.01.02X, this cycle was rerun correctly as 1.01.0B. Nevertheless, response data for cycle 1.01.02X are valid for the concentrations used.

peak corresponding to when the maximum amounts of divalent ions are being absorbed.

3. The sodium-concentration peak is followed by the peak effluent concentrations of magnesium and then of calcium (the most strongly absorbed cation of the three) as the resin is exhausted of sodium.

4. The total exhaustion of the resin is essentially complete for a given feed-solution composition when the effluent composition matches the influent composition.

In the laboratory IX cycles, the exhaustion step was terminated when the calcium and magnesium concentrations measured in the effluent equaled their respective concentrations in the feed within the analytical precision of the titrimetric methods for calcium and total hardness of approximately 1 meq/L. During cycle 1.01.06, this occurred after 127 bed volumes of feed solution had passed through the resin bed as shown on figure 6. Corresponding specific resin capacities were calculated to be q_{Ca}= 1.31 eq/L and q_{Mg} = 0.36 eq/L. Because these specific resin capacities were measured for conditions of approximate equilibrium between solution and resin, they should be only a function of the ionic equilibrium relations between the solution and cation-exchange resin and not the flow rates and temperatures, which affect the shapes of the breakthrough curves.

Operating an IX column until approximate equilibrium between the exhausting solution and IX resin differs from usual operation as discussed previously. In more typical IX operation, the exhaustion is terminated usually when a given breakthrough concentration in the effluent — as determined by product-water-quality requirements — is reached. Under these breakthrough restraints the specific resin capacities are a function of how fast the breakthrough occurs, which is a function of the flow rates and temperatures, for example, in addition to the equilibrium capacities as discussed in the previous paragraph. The calcium-breakthrough concentrations allowed before terminating exhaustion in the field experiments were 6 meq/L when operating the desalting equipment at 80 percent recovery and 12 meq/L when operating at 92 percent recovery.

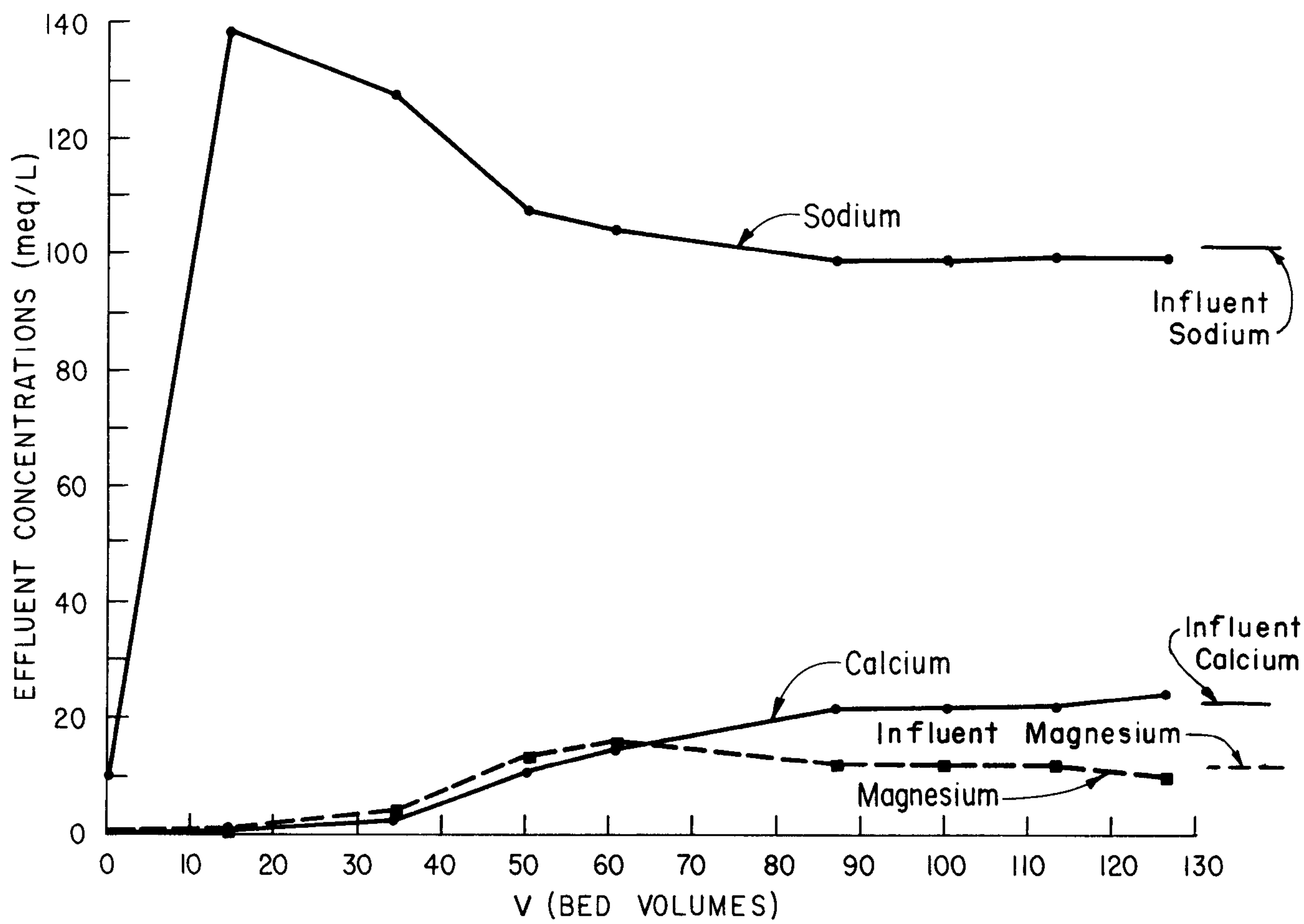

Figure 6. – Cationic effluent concentrations during exhaustion of cycle 1.01.06.

The effect of terminating the exhaustion prior to equilibrium can be demonstrated with the laboratory data. For example, in cycle 1.06.01 — by interpolating the data in figure 6 — a 6-meq/L of calcium breakthrough corresponded approximately to the passage of 41 bed volumes of effluent, $q_{Ca} = 0.90$ eq/L, and $q_{Mg} = 0.40$ eq/L. At a breakthrough concentration of 12 meq/L of calcium, interpolation yielded 53 bed volumes of exhaustion effluent $q_{Ca} = 1.07$ eq/L and $q_{Mg} = 0.41$ eq/L. These lower q_{Ca} and higher q_{Mg} using a calcium breakthrough concentration relative to the equilibrium q_{Ca} are totally expected. The reason for a lower q_{Ca} and a higher q_{Mg} (when exhaustion is terminated before equilibrium is reached) is that, as shown on figure 6, calcium breaks through last as it displaces magnesium from the resin, and thus, the net amounts of calcium absorbed by the resin is greater and of magnesium is less as final cationic equilibrium between resin and exhausting solution is approached.

Typical plots of calcium, magnesium, and sodium concentration versus resin-bed-effluent volume are given on figure 7 for the regeneration step of cycle 1.01.06. Upon analyzing the data, it was concluded that the regeneration effluent concentrations on figure 7 and for the other laboratory IX cycles were not measured frequently enough to accurately define the curves near the beginning of regeneration, where the calcium and magnesium concentrations quickly reach their peak and are changing at their greatest rates. Consequently, the measured area under the curves do not accurately represent the amounts of ions eluted during regeneration.

This rapid appearance of the effluent concentration maxima of calcium and magnesium during regeneration are understood more easily from the estimate that only 1.7 bed volumes of regenerant solution contained the necessary equivalents of sodium to match the total capacity of the resin bed during cycle 1.01.06. Put another way, only 1.4 bed volumes of regenerant would have been required to remove the calcium and magnesium from the resin bed, based on their resin capacities measured in the experiments, if all of the sodium entering in the regenerant had been exchanged for the calcium and magnesium removed from the resin during regeneration. Yet, the second effluent sample was collected after 2.5 bed volumes of effluent; and in the third sample at 6.8 bed volumes the calcium concentration already was approaching the influent concentration. With sufficient data it would have been possible to measure precisely the balance between the amount of each cation removed by the resin during the exhaustion with the amount eluted during regeneration, but this

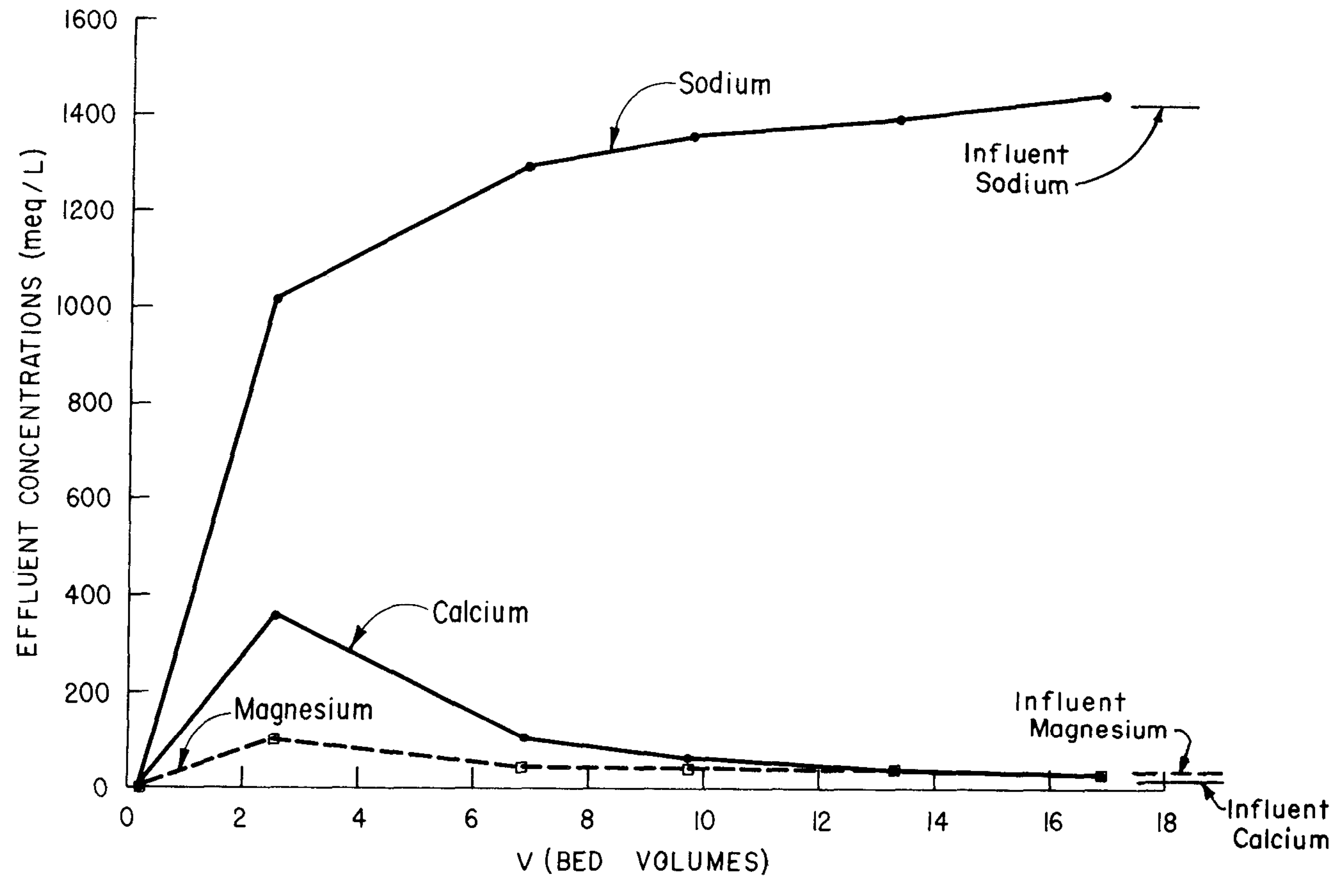

Figure 7. – Cationic effluent concentrations during regeneration of cycle 1.01.06.

was not possible with the data shown on figure 7 nor with the data from the regeneration steps of the other experimental IX cycles.

Because these mistakes in selecting the regeneration-effluent-sampling times were not recognized until the experimentation on nearly all IX cycles was completed, it was not possible to redo any of the cycles within the time and money constraints. Fortunately, exhaustion-effluent-concentration histories — as presented earlier in this section — are more important in defining IX performance because they define the resin capacities that are the regeneration-effluent concentrations.

A summary of resin-capacity data for each experimental IX cycle is given in table 6. Cycles 1.01.02X and 1.02.01 were added to the original experimental design. For cycle 1.01.01A, there are data available only for the exhaustion step. For 1.01.08B, there was not a complete cycle but only a regeneration in preparation for the succeeding exhaustion in cycle 1.02.01. The *original design* refers to the eight remaining cycles referred to in tables 5 and 6. Complete sets of experimental data for each laboratory IX cycle are contained in appendix F.

Multiple linear regression analysis. – The analysis [25] was performed on the dependent variables shown in table 6 and the independent variables in table 5. The "F" test and 95 percent confidence limits were used to gage statistical significance of the regressions. The data from all 10 cycles were analyzed by stepwise regression with the specific resin capacity q_{Ca} at equilibrium as the dependent variable. A significant fit was found with the independent variables C'_{Na} for the regenerant and C'_{Ca} for the exhaustion feed according to:

$$q_{Ca} = 0.000\,515\ C'_{Na} + 0.0131\ C'_{Ca} + 0.344 \quad (8)$$

The regression analysis showed that flow rate and temperature had no significant effect on q_{Ca}, which would be expected because flow rate and temperature should affect only the shape of the exhaustion-effluent concentration curves.

It is not surprising that increasing the sodium concentration in the regenerant increases q_{Ca}, as indicated by the first term in the right side of equation 8. It also would be expected that the calcium concentration of the feed would increase q_{Ca}, as shown by the second term of the right side, provided that there was not a simultaneous increase in the sodium concentration of the feed water. More illuminating and ultimately more useful expressions for q_{Ca}, as a function of water composition than equation 8, are given in the following section on IX modeling.

Regression analysis on q_{Ca} (table 6) where an exhaustion-breakthrough concentration of 6 meq/L of calcium would be used yielded a significant relation with q_{Ca} at equilibrium only, a rather interesting finding since it was expected that exhaustion-flow rate would be important. The effect of flow rate is discussed further in the section on modeling.

Using the data in table 6, the ratio of q_{Ca} at a 6- or 12-meq/L of calcium breakthrough concentration to the equilibrium q_{Ca} reflects the fraction of the total

Table 6. – *Specific resin capacities from laboratory experiments*

Cycle number	Exhaustion breakthrough criteria	Exhaustion throughput bed volumes*	Specific resin capacities, eq/L: Calcium	Magnesium
1.01.01A	6 meq/L calcium	56	1.14	0.37
	12 meq/L calcium	69	1.31	0.35
	Equilibrium	262	1.38	0.14
1.01.01B	6 meq/L calcium	37	0.83	0.70
	12 meq/L calcium	49	1.01	0.83
	Equilibrium	116	1.26	1.56
1.01.02X	6 meq/L calcium	54	1.14	–0.21
	12 meq/L calcium	62	1.26	–0.32
	Equilibrium	92	1.43	–0.71
1.01.02B	6 meq/L calcium	29	1.18	0.22
	12 meq/L calcium	32	1.29	0.23
	Equilibirum	67	1.62	0.16
1.01.03	6 meq/L calcium	42	1.00	0.25
	12 meq/L calcium	54	1.20	0.26
	Equilibrium	100	1.51	0.05
1.01.04	6 meq/L calcium	37	0.78	0.33
	12 meq/L calcium	44	0.87	0.31
	Equilibrium	86	0.99	0.29
1.01.05	6 meq/L calcium	20	0.71	0.16
	12 meq/L calcium	25	0.87	0.20
	Equilibrium	79	1.14	0.10
1.01.06	6 meq/L calcium	41	0.90	0.40
	12 meq/L calcium	53	1.07	0.41
	Equilibrium	127	1.31	0.36
1.01.07	6 meq/L calcium	15	0.56	0.12
	12 meq/L calcium	19	0.70	0.14
	Equilibrium	92	1.04	0.23
1.01.08	6 meq/L calcium	23	0.84	0.21
	12 meq/L calcium	26	0.96	0.22
	Equilibrium	76	1.29	0.18
1.02.01	6 meq/L calcium	63	1.38	0.52
	12 meq/L calcium	71	1.47	0.47
	Equilibrium	103	1.56	0.41

* Resin bed volume was 0.5L.

calcium resin capacity that was realized under a set of operating conditions. Using a 6-meq/L calcium-breakthrough concentration, this ratio had a mean of 0.667 with a standard deviation of 0.073 for the eight cycles of the basic design. With a 12-meq/L calcium-breakthrough concentration, the ratio had a mean of 0.784 and a standard deviation of 0.060. These two values of the ratio and the relatively small standard deviation agree with a rule of thumb that 70 percent of the total resin capacity is often realized in a practical ion-exchange process.

Comparisons between laboratory and LVS-field IX data. – Comparisons support the value of the laboratory experiments in obtaining resin capacities in lieu of field experiments. The most relevent comparisons are for specific resin capacities q_{Ca} in tables 3 and 6. With reject-brine regenerant at 80 percent desalting recovery, the calcium specific resin capacity reached a maximum of 0.86 eq/L (cycle L.04.11 table 3) using the most favorable recommended operating procedures. For the only cycle with comparable feed water and regenerant compositions in the laboratory experiments, cycle 1.01.04 q_{Ca} was 0.87 (table 6) having a breakthrough concentration of 12 meq/L of calcium comparable to that used in cycle L.04.11 at LVS. With reject-brine regenerant from 92 percent recovery desalting, the resin capacity averaged 1.03 eq/L at LVS for the last 11 cycles listed in table 3. Comparable laboratory IX cycles (listed in table 6) having similar water compositions include cycles 1.01.01B, 1.01.03, and 1.01.06 which had q_{Ca}'s of 0.83, 1.00, and 0.90 eq/L, respectively, for a breakthrough concentration of 6 meq/L of calcium — the same as that used at the higher desalting recovery at LVS. Note that cycle 1.01.03, which had the closest q_{Ca} of the three cycles to the average field q_{Ca}, also was the only cycle of the three which used the lower level exhaustion flow rate which was closer to the exhaustion flow rate used in the field. Thus, the laboratory experiments successfully obtained specific resin capacities for calcium at comparable calcium-breakthrough concentrations in the effluent that agree with those obtained at the LVS site. The agreement is particularly interesting because no gypsum formed during regeneration with sulfate-free solutions in the laboratory experiments but considerable gypsum formed during the regenerations at the LVS site.

Lime treatment prior to IX. – The lime treatment prior to IX is not needed at LVS for pretreatment removal of calcium according to the laboratory IX results. It is interesting to note that when aerated, raw LVS water was simulated as the IX feed water (table 6) the values of q_{Ca} were comparable to the values when aerated, lime-treated feed water was simulated.

The amount of cation-exchange resin required in an IX plant to pretreat the LVS flow of 19.6 m^3/min was estimated for aerated, lime-treated LVS water and for aerated only (carbon-dioxide gas removed) LVS water. Equations 3 and 4 were used with IX-step durations from cycle L.22.15 of the LVS field experiments. A specific calcium resin capacity of 1.0 eq/L was assumed in arriving at the following calculated results:

	Lime treatment	*No lime treatment*
Feed-water calcium concentration, meq/L	22	42
Effluent calcium concentration, meq/L	6	6
Calcium concentration removed, meq/L	16	36
Exhausion duration, min	178	79
Fresh regeneration duration, min	14	6
Cycle duration, min	250	143
Volume of resin required, m^3	78	101

Thus, about 29 percent more cation-exchange resin would be required at LVS if lime-treatment were omitted prior to IX which would no doubt be less expensive than the additional lime-treatment system.

Besides partial softening, lime treatment and filtration also provide clarification of suspended material and removal of silica if high lime dosages are added to raise the pH above 10. Suspended material was not present in the LVS well water.

Because silica was at a concentration of about 30 mg/L in the aerated well water [2] and it can precipitate at concentrations above 115 mg/L if in amorphous form [26], a silica-concentration factor of less than 3.8 would be safe corresponding to a desalting recovery of about 74 percent if silica were fully rejected by the desalting process. Because silica is not effectively concentrated by electrodialysis at neutral pH [7], the recovery of an electrodialysis at LVS would not be limited by a silica concentration in the feed water of 30 mg/L; if the IX pretreatment is for reverse osmosis of cooling tower use, the concentration factor of the dissolved solids without any potential for silica scaling is only about four. However, this concentration factor could be higher than four depending upon the species of silica [26] and their proportions present in the LVS water; therefore, only future experimental work can determine the precise concentration limit at the onset of silica scaling at LVS and whether silica removal is absolutely necessary.

ION-EXCHANGE MODELS

Introduction

Models to predict cation-exchange resin capacity and the resin-bed breakthrough profile of calcium during exhaustion were studied in the present work. Numerous models of the ion-exchange process have been developed by others [27, 28, 29, 30]. There is no single model capable of generally describing all IX processes in terms of equilibrium and kinetics. For each ionic solution-resin system, it is necessary to select a correct model from among the different models possible based upon which of the assumptions incorporated in the models are valid in the particular situation. Two types of models include those which predict ionic equilibrium between the IX resin and solution and those which describe the rate of achieving exhaustion or regeneration of the resin under a set of operating conditions.

1. An equilibrium model was used to predict the net amount of calcium, magnesium, and sodium that can be exchanged at equilibrium between DOWEX® HCR cation-exchange resin and ionic solutions of different LVS exhaustion and regeneration compositions.

2. The equilibrium model was also extended to predict the leakage concentrations of calcium and magnesium at the beginning of the exhaustion step of an IX cycle.

3. A model which takes into account the mass-transfer resistance of the stagnant liquid film between the bulk solution and the resin-bead surface was fit to laboratory IX data to try to predict the shape of the exhaustion calcium-breakthrough curve.

Comparisons between results of the three models and data from the LVS field and laboratory experiments (described in the previous two sections) are given in separate *results* sections, which follow each of the descriptions of the three models.

Also, it would be desirable to have a model for the regeneration step. Future study is recommended to develop a model to describe regeneration when the regenerant brine is a mixture and the regenerant volume is limited. Suggestions on developing a regeneration model are included at the end of this section.

Cation-Exchange Equilibrium

Equilibrium between ions in an aqueous solution and ions absorbed in an ion-exchange resin can be expressed by a form of the *law of mass action.* In the following equations, it is assumed that activity coefficients of the ions in the solution and resin are equal to 1.0. Estimates of the activity coefficients in the solution are possible from data in the literature. But activity coefficients in the resin phase cannot be measured directly, and limited data are available in the literature. In all the equations in this section, it is assumed that potassium behaves similar to and is combined with sodium in the calculations whereby the equivalents per liter of sodium include the equivalents per liter of sodium plus potassium.

For the ternary ionic system calcium-magnesium-sodium the catonic equilibrium between resin and solution can be expressed according to the *law of mass action* [27, 31] for mono-divalent exchange by the following three equations:

$$\frac{Y_{Ca}}{X_{Ca}}\left(\frac{X_{Na}}{Y_{Na}}\right)^2 = \frac{K_{Ca/Na}\,Q}{C_o} \tag{9}$$

$$\frac{Y_{Mg}}{X_{Mg}}\left(\frac{X_{Na}}{Y_{Na}}\right)^2 = \frac{K_{Mg/Na}\,Q}{C_o} \tag{10}$$

$$Y_{Ca} + Y_{Mg} + Y_{Na} = 1 \tag{11}$$

where:

Y_{Ca} = equivalent fraction of resin in the calcium form,
Y_{Mg} = equivalent fraction of resin in the magnesium form,
Y_{Na} = equivalent fraction of resin in the sodium form,
X_{Ca} = equivalent fraction of calcium in the solution,
X_{Mg} = equivalent fraction of magnesium in the solution,
X_{Na} = equivalent fraction of sodium in the solution,
$K_{Ca/Mg}$ = selectivity coefficient of calcium relative to sodium,
$K_{Mg/Na}$ = selectivity coefficient of magnesium relative to sodium,
Q = total cation-exchange capacity of the resin in equivalents per liter of resin and,
C_o = total normality of the solution.

A mass-action equation for the cation exchange of calcium and magnesium can be written also but is not independent of equations 9, 10, and 11:

$$\frac{Y_{Ca}\,X_{Mg}}{X_{Ca}\,Y_{Mg}} = K_{Ca/Mg} \tag{12}$$

Equation 12 can be derived by dividing equation 9 by equation 10 where the selectivity coefficient for calcium relative to magnesium is given by:

$$K_{Ca/Mg} = \frac{K_{Ca/Na}}{K_{Mg/Na}} \tag{13}$$

Note that C_o and Q do not affect the calcium-magnesium-resin equilibrium according to equation 12, which occurs, according to the law of mass action and confirmed by experimental data, because the ions of calcium and magnesium have the same valence.

To solve equations 9, 10, and 11 simultaneously, a combination of the three equations yields:

$$Y_{Na} = \frac{(1 + 2A)^{1/2} - 1}{A} \tag{14}$$

where:

$$A = \frac{2\,Q}{C_o\,(X_{Na})^2}(K_{Ca/Na}\,X_{Ca} + K_{Ca/Mg}\,X_{Mg}) \tag{15}$$

Calculation of the ionic form of the resin proceeds in the following sequence:

1. X_{Ca}, X_{Mg}, and X_{Na} are calculated from the solution cationic composition.

2. Y_{Na} is calculated from equations 14 and 15.

3. Y_{Ca} is calculated using equation 9, rearranged.

4. Y_{Mg} is calculated from equation 11.

The concentration in the resin (same as the specific resin capacity) of each cation i is calculated from:

$$q_i = Y_i\,Q \tag{16}$$

The net equilibrium resin capacity of a cycle — that is, regenerating the resin to equilibrium with one solution composition and exhausting to equilibrium with another solution — is calculated by taking the difference between the q_i's of the regeneration and exhaustion calculated using equation 16. In the present work the properties used for DOWEX® HCR-W2 were:

$Q = 2.0$ eq/L (see manufacturer's data in app. A),
$K_{Ca/Na} = 3.0$, and
$K_{Mg/Na} = 1.2$ (see reference [31])

These K values from the literature were from experiments with DOWEX® 50-X8, which according to the manufacturer has the same chemical composition and is otherwise essentially the same as the newer model designation HCR-W2. Experiments to evaluate the accuracy of the law of mass action for the calcium-magnesium-sodium-DOWEX® HCR-W2 system and the experimental values for the equilibrium constants for this system are being completed at the E&R laboratory in an additional phase of the present study. Results of this additional work will be in a separate report.

Note that equations 9 and 10 predict strong preference for divalent calcium and magnesium absorption over monovalent sodium at low solution concentrations C_o; but at high solution concentrations, sodium is preferred by the resin over the divalent cations. It is this fact that makes water softening by cation exchange so successful, even when a reject brine containing a mixture of cations, including some of the same divalent cations to be eluted from the cation-exchange resin, is used to regenerate the resin.

Results. – Specific resin capacities predicted by the equilibrium model for each of the laboratory cycles is in the fourth column of table 7. Complete computer printouts from the calculations are in appendix G. These predicted resin capacities were calculated from the equations and the HCR resin data earlier in this section plus the water compositions in table 5. For easy comparison, the third column of table 7

Table 7. – *Comparison among measured and predicted equilibrium resin capacities for the laboratory experiments*

		Specific resin capacities, eq/L			
Cycle number	Cat-ion	Experi-mental trapezoidal integration	Equi-librium model predict.	Experi-mental liquid-film model	Experi-mental half-height integration
1.01.01A	Ca	1.38		1.36	1.44
	Mg	0.14			
1.01.01B	Ca	1.26	0.99	1.12	1.23
	Mg	1.56	0.36		
1.01.02X	Ca	1.43	1.37	1.34	1.41
	Mg	–0.71	–0.04		
1.01.02B	Ca	1.62	1.39	1.56	1.76
	Mg	0.16	0.04		
1.01.03	Ca	1.51	1.29	1.45	1.55
	Mg	0.05	0.07		
1.01.04	Ca	0.99	0.87	0.96	1.03
	Mg	0.29	0.12		
1.01.05	Ca	1.14	1.11	1.06	1.15
	Mg	0.10	–0.002		
1.01.06	Ca	1.31	1.18	1.10	1.16
	Mg	0.36	0.20		
1.01.07	Ca	1.04	1.05	0.96	1.06
	Mg	0.23	–0.02		
1.01.08	Ca	1.29	1.19	1.15	1.27
	Mg	0.18	0.01		
1.02.01	Ca	1.56	1.31	1.46	1.50
	Mg	0.41	0.26		

repeats the experimental equilibrium resin capacities given in table 6. The last two columns of table 7 are discussed after the liquid-film model later in this section.

Comparing the 11 pairs of corresponding specific resin capacities (from columns three and four in table 7) indicated that the average percent difference between the equilibrium-model predictions and the experimental data for the calcium specific resin capacity was 10 percent (relative to the experimental value) with a standard deviation of 7 percent. For magnesium, the mean percent difference between experimental and predicted specific resin capacities was minus 77 percent having a standard deviation of 24 percent. Thus, the equilibrium model did a better job of predicting the calcium resin capacity, which is of greater practical interest, than the magnesium resin capacity.

The resin capacities calculated using the equilibrium model are not entirely comparable to the calcium resin capacities measured at the LVS site (which are listed in table 3) because the exhaustion of the cation-exchange resin in the field experiments was always terminated at a calcium-breakthrough concentration disallowing complete equilibrium between feed solution and resin. With 80 percent recovery desalting reject as the regenerant, comparisons between specific resin capacities predicted using the equilibrium model and values obtained experimentally — listed in table 3, for calcium and in appendix B, for magnesium — are as follows:

Cation	*Specific resin capacities, eq/L*			
	Model		Experimental	
	Mean	S.D.	Mean	S.D.
Calcium	0.92	0.02	0.72	0.12
Magnesium	0.09	0.02	0.20	0.02

With 92 percent desalting reject regenerant the comparable values are:

Cation	Model		Experimental	
	Mean	S.D.	Mean	S.D.
Calcium	1.18	0.04	1.03	0.05
Magnesium	0.13	0.08	0.28	0.06

S.D. is an abbreviation for standard deviation.

With 92 percent desalting reject regenerant the comparable values are:

It would be expected that the calcium resin capacities in the field experiments would be lower than predicted at equilibrium. Conversely, it would be expected that the predicted magnesium capacities would be greater than experimental values because calcium in solution exchanges with magnesium in the resin during the final approach to equilibrium between resin and solution. Thus, the above data show that the model and experimental values vary from one another as expected.

In summary, the equilibrium model, based on the *law of mass action* and assuming activity coefficients of 1.0, predicted resin capacities for calcium and magnesium that were lower than experimental results for LVS water compositions done in the laboratory and field. Further work is needed to improve the accuracy of the equilibrium model including different resins and especially a range of water compositions. Experimental work in the Bureau's E&R laboratory is accomplishing this.

Initial Resin-Bed Leakage

The initial leakage concentrations from a cation exchange bed have been estimated using the equilibrium model for the case of countercurrent regeneration-exhaustion. At the beginning of a downflow exhaustion following an upflow regeneration, the bottom of the resin bed will be in ionic equilibrium with the regeneration solution — even if the regeneration is not to complete equilibrium throughout the bed. If the regeneration solution consists only of sodium cations the initial leakage will consist essentially of sodium cations only — assuming that hydrodynamic effects are a relatively small contribution to leakage. In the present case of regeneration with a brine containing a mixture of cations, the regenerated resin will contain a proportion of that mixture. Thus, the initial composition of the exhaustion effluent solution will also contain a mixture of the cations in proportions determined by the composition of the regenerant, the total normality of the exhausting solution, and the cationic equilibrium between solution and resin. Moreover, following an effective rinse in which the residual regeneration solution is flushed from the bed, the initial leakage concentration of the exhaustion effluent solution will have the same C_o as the exhaustion influent but an ionic composition which is in equilibrium with the resin in the bottom of the regenerated bed.

These relations are demonstrated in the following equations. By solving equations 9 and 10 simultaneously in terms of X_{Na} the result is:

$$X_{Na} = \frac{(1 + 2B)^{1/2} - 1}{B} \qquad (17)$$

where:

$$B = \frac{2\ C_o}{Q\,(Y_{Na})^2}\,(Y_{Ca}/K_{Ca/Na} + Y_{Mg}/K_{Mg/Na}) \qquad (18)$$

Also,

$$X_{Ca} + X_{Mg} + X_{Na} = 1 \qquad (19)$$

and for each cation (i = Ca, Mg, or Na)

$$C_i = X_i\, C_o \qquad (20)$$

The calculation of the initial concentrations in the exhaustion effluent procede in the following order:

1. Y_i's for the resin in equilibrium with the regenerant solution are calculated as given above using equations 9 through 15 and the steps outlined in the previous section.

2. X_{Na} is calculated from equations 17 and 18.

3. X_{Ca} is calculated from equation 9 rearranged.

4. X_{Mg} is calculated from equation 19.

5. The initial leakage concentrations, C_{Ca}, C_{Mg}, and C_{Na} are calculated from equation 20.

It is interesting to note that when the bottom of the resin bed has been brought to equilibrium with a regeneration solution, which determines the values of the Y_i's of the resin in the bottom of the bed, the initial composition of the effluent of the exhaustion step is calculated only from the total normality C_o of the exhausting solution, and is not a function of the relative amounts of different cations in the exhausting feed water.

Results. – Initial exhaustion composition was predicted using the preceding equations and compared to experimental values from the laboratory and LVS field experiments. Table 8 compares the laboratory experiments. A complete set of computer printouts of the equilibrium model calculations are in appendix G. The compositions used in the equilibrium model calculations are the ones listed in table 5. For calcium, the initial exhaustion leakage concentrations predicted by the model were 30 percent lower than the experimental result (a mean of the 10 cycles listed in table 8) and a standard deviation of 25 percent. For magnesium, the predicted leakage concentration averaged 49 percent lower than experimental

Table 8. – *Measured and predicted compositions of initial leakage from exhaustion of ion exchanger during laboratory experiments*

Cycle number	Initial exhaustion-leakage concentrations, meq/L					
	Experimental			Equilibrium model		
	Ca	Mg	Na	Ca	Mg	Na
1.01.01B	0.78	1.57	137	0.37	0.43	154
1.01.02X	0.30	2.56	126	0.25	0.18	116
1.01.02B	0.40	0.70	151	0.30	0.57	152
1.01.03	0.40	0.80	131	0.24	0.44	136
1.01.04	1.20	1.50	127	1.23	1.28	136
1.01.50	1.50	1.70	144	1.29	1.32	141
1.01.06	0.20	0.70	139	0.22	0.33	137
1.01.07	3.98	5.92	115	1.60	1.55	130
1.01.08	1.80	1.33	138	0.89	1.13	143
1.02.01	0.02	0.05	130	0.01	0.01	129

values having a standard deviation of 30 percent. The relatively large standard deviations indicate considerable scatter in the goodness of fits of the model or variation in the experimental data.

Table 9 shows similar comparisons of initial leakage compositions for the field experiments. For 16 of the 18 cycles listed in table 9 (cycles L.18.13 and L.19.27 omitted for the reason given in table 9 footnote), the calcium-leakage concentration predicted by the equilibrium model for each cycle averaged 76 percent less than the corresponding experimental value with a standard deviation of 11 percent. For magnesium the predicted leakage concentration averaged 53 percent less than the measured values from LVS with a standard deviation of 17 percent.

The reasons possible why the equilibrium model underpredicted the initial concentrations of calcium and magnesium during exhaustion are that:

1. The equilibrium model does not account for nonunit activity coefficients in the cationic equilibrium between resin and solution.

2. The higher than predicted initial leakage during exhaustion is due to the hydrodynamics of flow through the resin bed whereby a certain proportion of the feed water avoids intimate contact with the resin.

Table 9. – *Measured and predicted compositions of initial leakage from exhaustion of ion exchanger during ion-exchange experiments at the La Verkin Springs site*

Cycle number	Initial exhaustion leakage concentrations, meq/L					
	Experimental			Equilibrium model		
	Ca	Mg	Na	Ca	Mg	Na
L.01.97	3.24	2.01	134	1.08	1.19	137
L.02.12	2.50	2.01	134	1.01	1.25	140
L.03.35	2.74	2.01	137	0.96	1.17	138
L.04.11	2.50	2.26	139	0.85	1.26	132
L.05.54	4.74	3.01	134	0.26	0.31	141
L.10.14	1.25	1.51	143	0.15	0.42	140
L.12.22	1.20	0.82	190	0.11	0.31	137
L.17.17	0.80	1.56	140	0.15	0.53	135
L.18.13	0.40	0.48	160	*0.45	*1.49	132
L.19.27	0.36	0.60	160	*0.38	*0.66	135
L.20.09	0.56	0.95	164	0.11	0.58	130
L.22.15	0.48	0.72	160	0.15	0.45	136
L.23.19	0.70	0.76	160	0.26	0.47	137
L.24.11	0.64	0.80	166	0.19	0.41	134
L.25.22	1.80	1.81	150	0.38	1.04	135
L.26.14	1.40	1.56	160	0.21	0.46	134

* High predicted values of calcium and magnesium leakage for cycles L.18.13 and L.19.27, as compared to similar cycles, is attributed to errors in the chemical analyses of the fresh regenerant. The reported concentrations of calcium and magnesium in the fresh regenerant of the two cycles was up to 4 times higher than the value that would be expected.

3. The experimental estimates of calcium and magnesium concentration in the exhaustion effluent, done by atomic absorption spectrometry in two different chemistry laboratories, are systematically higher than actual. Atomic absorption spectrometry are subject to such systematic errors when the solutions analyzed contain interfering ions. Calcium analyses of the exhaustion effluent done by operators during each cycle to detect the resin breakthrough to terminate exhaustion yielded values that were about half of the experimental values listed in table 9. Laboratory data for calcium in table 8 also were done by the titration method.

The effect of the second factor is apparent in comparing the leakage concentrations of the field experiments (table 9) with results measured in the laboratory (table 8), even if a correction for the analytical method (factor 3 above) is included. The initial calcium concentrations from the field experiments were several times greater than the laboratory measurements. Ion-exchange equilibria differences (reason 1 above) is not a likely reason for the differences in leakages measured in the laboratory and in the field because the water compositions and resin tested in each location were similar. Rather, it is thought that the narrower column (25 millimeters in diameter) and flow distributors used in the laboratory provided more uniform axial flow distribution across the cross section of the resin bed than did the larger pilot plant column (340 millimeters in diameter) and flow distributors used in the field. There were also larger differences in temperature between feed water and regenerants at LVS that apparently contributed to a moderate amount of instability of flow and turbulence in the resin bed — visible through the transparent column — when solutions of different density flowing through the resin bed were changing between IX steps.

Hydrodynamic aspects of IX columns are divided generally into effects caused by eddy dispersion and from flow maldistribution [28, 29]. Eddy dispersion is a longitudinal spread of the solutes (ions), which occurs because the fluid follows a meandering path, changing direction as it flows through the packed resin bed. Eddy dispersion becomes insignificant with the decrease in size of the column packing. Flow maldistribution can be caused by nonuniformities in the column-packing density. The flow will naturally take the path of least resistance, which corresponds to the least dense packing, which generally occurs near the outside wall of the column. Shrinkage of the resin during absorption of ions accentuates the problem. The DOWEX® HCR cation-exchange resin swells in going from the sodium to magnesium form; then it shrinks in going from the magnesium to calcium form [28]. Fingering of flow also can be caused by differences in fluid density during the transition between different solutions fed to the resin bed.

It is apparent that some improvement of the equilibrium model is necessary, particularly in moderate to large diameter resin beds, for the model to be accurate in predicting the initial composition of the exhaustion effluent. Further work is required to identify how this correction should be done. Nevertheless, the model given here does give a qualitative indication of the initial leakage to be expected.

Liquid-Film Mass-Transfer Control During Exhaustion

While the equilibrium relations in the previous two sections are useful in predicting the maximum capacity of an IX resin and the initial leakage in a particular application, such equilibria alone do not account for transitions between equilibrium states. Full equilibrium between resin and solutions are seldom, if ever, achieved in practical IX processes. In the transition between a fully regenerated resin bed and a fully exhausted resin bed, equilibrium relations for the case where the exhausting ion is preferentially absorbed from solution would predict a step change in the composition of the effluent solution between the initial leakage composition (estimated in the previous section) and the composition of the exhaustion feed water. In reality the transition is not abrupt as shown on figure 5 and data in appendixes B and F. Mass-transfer rate limitations cause the transitions between equilibrium states, which are seldom actually achieved, to be gradual.

Numerous models having analytic solutions have been developed to account for mass-transfer limitations for the movement of ions between the solution and IX resin [27 to 30]. Each of the analytical models are based on a set of assumptions to make the mathematics solvable. The validity and applicability of any particular model depend obviously upon how well the model represents the subject ion-exchange system. The modeling that follows applies to ion exchange in a fixed bed as opposed to mass transfer to a single bead.

A two-component system is considered here first because it is simpler than a polycomponent system. A model describing the transport of three or four cations could be much more accurate in the present case of calcium, magnesium, sodium, and potassium exchange than the two-component model. But such polycomponent models result in a set of simultaneous differential equations which cannot be solved analytically but require finite-difference, numerical solutions using a computer [29]. The development of such a model is beyond the scope of the present phase of study but is recommended for the future. Nevertheless, for the purposes of description and understanding, the simpler result and transport mechanisms of a two-component system are more easily discussed and explained.

Divalent-monovalent exchange (either calcium or magnesium being exchanged for sodium) can be approximated at relatively low solution normalities, such as in the exhaustion, as irreversible cation-exchange absorption of the divalent cation into the resin. This strongly favorable absorption of magnesium and calcium in a resin bed originally in the sodium form is demonstrated by the equilibria of equations 9 and 10 where $KQ/C_O >> 1$. Under such equilibrium conditions during exhaustion the shape of the divalent-ion-concentration profile passing through the bed, once developed at the entrance of the bed, is relatively stable and invariant in shape with variations in time and distance along the axis of flow through the resin bed. This type of profile is termed "self-sharpening," because effects such as axial dispersion which would otherwise broaden the exchange front tend to be canceled out.

In contrast, regeneration of the resin will be an unfavorable equilibrium when $KQ/C_O < 1$. Under such conditions the shape of the concentration profile will broaden with axial distance through the resin bed. While the resin bed can be regenerated successfully when the equilibrium is unfavorable, the volume of regenerant solution required is greater than if the regeneration were controlled by a favorable equilibrium. Thus, the same model that applies to exhaustion generally does not apply to regeneration, which is true of the present calcium-magnesium-sodium-DOWEX® HCR system. An equilibrium, mass-balnce model can account for much of the broadening of the regeneration concentration profiles within and leaving the resin bed [29].

For a given set of solution and resin ionic compositions and hydrodynamic flow conditions, the local ion mass-transfer rates are controlled by the ionic equilibrium between solution and resin, which determines the mass-transfer driving forces, the mass-transfer resistance of the ion-exchange material itself, and the resistance of the "liquid film" of solution in the immediate vicinity of the resin beads. Axial dispersion is often negligible relative to the preceding mass-transfer resistances. In the present case of a strong acid cation-exchange resin being exhausted by a relatively dilute solution, the liquid-film mass-transport resistance dominates, at least during the beginning portion of exhaustion, which is of greatest interest because it includes the practical range of operation of an ion exchanger up through breakthrough concentration when the exhaustion step is terminated. As exhaustion procedes further and equilibrium between resin and exhaustion-effluent solution is approached, the mass transport within the resin beads begin to dominate the overall ionic mass transport between solution and resin.'

There is a relatively simple mathematical model for irreversible exchange in a fixed bed of a strongly favored species for an absorbed species [29, 30, 32, and 33]. The model is for two ionic components only, but it should approximate the present system where either calcium or magnesium is exchanged for sodium during exhaustion. It would not apply to the calcium-magnesium exchange because calcium is preferred only moderately by the resin over magnesium (see equation 12).

To develop the liquid-film model it was assumed that:

1. The resin initially contains only the monovalent cation as does the portion of resin before the exchange front arrives,

2. The solution contains only the divalent cation as does the resin behind the exchange zone,

3. Liquid-film resistance controls the mass transport, and

4. The equilibrium for absorption of the divalent ion is strongly favorable relative to the monovalent ion such that the liquid-film divalent-ion concentration at the resin surface is essentially zero.

The differential equation for the exchange zone is:

$$\frac{dC}{dt} = k_L C \tag{21}$$

The solution of equation 21 for the composition of the effluent of the exchange zone leaving the resin bed, subject to a mass balance between the solution and resin [32, 33] yields:

$$\ln \frac{C}{C_o} = \frac{k_L C_o}{aG_e} V - \frac{k_L V_{resin}}{G} - 1 \tag{22}$$

where:

C = effluent concentration of the divalent ion in meq/L,
C_o = influent concentration of the divalent ion in meq/L,
k_L = liquid-film mass transport coefficient in min^{-1},
a = total resin capacity in eq/L of resin,
G_e = exhaustion flow rate in L/min,
V = volume of solution passed through the resin in L, and
V_{resin} = volume of resin in the bed in L.

Note that in the nomenclature above that k_L includes a factor for the film surface area per volume of resin bed. Because electroneutrality of ionic charges requires that the net equivalents of cations moving in a direction be balanced by an equal number moving in the opposite direction, the k_L is an average of the individual sodium and calcium transport coefficients. As used here, V includes a correction for the void volume of the bed. For example, if the void volume fraction of the resin bed is 0.3, the resin-bed volume times 0.3 is subtracted from each value of the accumulated exhaustion-effluent volume V to account for rinse water in the voids of the bed at the start of exhaustion.

It is interesting that the equilibrium constant $K_{Ca/Na}$ or $K_{Mg/Na}$ in equation 9 or 10 does not appear in equation 22. This is because it was assumed in deriving equation 22 that the divalent ion is very strongly absorbed preferentially by the resin, which is equivalent to stating that $K_{Ca/Na}$ or $K_{Mg/Na}$ is very large.

According to equation 22 (a semilog plot of C/C_o) the fraction of the divalent-ion concentration of the influent that breaks through the column in the effluent, versus V, the accumulated volume of solution passed through the column during exhaustion will yield a straight line with a slope of $k_L C_o/aG_e$ and an intercept of $-(k_L\ V_{resin}/G_e) - 1$. Because G_e, V_{resin}, and C_o are controlled and measureable in an experiment, k_L and a can be calculated from measurements of the slope and intercept. Thus, if equations 21 and 22 represent an accurate model, a laboratory-scale column can be operated to obtain data for the exhaustion of a sample of resin, and the k_L obtained from the data can be used to predict the exhaustion breakthrough curve (equation 22 rearranged in terms of C as a function of V) and the resin-volume requirement for a full-size plant. Furthermore, by collecting data at different experimental conditions it should be possible to obtain relations for k_L as a function of different control conditions (for example flow rate) to predict IX performance for a range of operating conditions.

The above two-ionic-component liquid-film model obtained from the literature was expanded to be more relevent to the present work. Specifically, the laboratory experiments included resin and solution compositions which were mixtures, not completely consistent with the assumptions used in deriving equation 22.

1. The cation-exchange resin was not totally in the monovalent form at the beginning of exhaustion (the previous assumption 1) but contained a particular proportion of the divalent and monovalent cations uniformly throughout each resin bead, and

2. The exhausting solution contained not just the divalent cation (the previous assumption 2) but was a mixture of the monovalent and divalent cations.

The initial and final compositions during exhaustion of the resin are described by the following nomenclature for a two-component, monovalent-divalent system. The resin begins exhaustion with q_i equivalents per liter of the divalent ion. The initial concentration of the monovalent ion in the resin is $a - q_i$. The initial concentration of the divalent ion in the exhaustion effluent is C_e, which is the solution concentration in equilibrium with the initial resin concentration of q_i. The initial sodium-leakage concentration in equilibrium with the resin is $C_o - C_e$. When exhaustion is complete, the resin will have reached an equilibrium divalent-ion concentration of q_e (a monovalent-ion concentration of $a - q_e$) with the exhaustion-feed solution having a concentration of C_i of the divalent ion ($C_O - C_i$ of the monovalent ion).

From the differential equation analagous to equation 21, a solution was derived analagous to equation 22:

$$\ln \frac{C - C_e}{C_i - C_e} = \frac{k_L (C_i - C_e)}{G_e (q_i - q_e)} V - \frac{k_L\ V_{resin}}{G_e} - 1 \qquad (23)$$

Values for k_L and $q_i - q_e$ can be obtained from a semilogarithmic plot of $(C - C_e) / (C_i - C_e)$ versus V. The slope will be:

$$\frac{k_L\ (C_i - C_e)}{G_e\ (q_i - q_e)}$$

and the intercept will be:

$$-\frac{k_L\ V_{resin}}{G_e} - 1$$

Note that the difference between q_i and q_e is obtained from the slope and intercept but that additional experimental data are needed to calculate individually the initial and final resin compositions. An additional possibility if the experimental data are unavailable is that the values of q_i and q_e can be estimated from solution compositions using the equilibrium model presented earlier in this section.

Besides the liquid-film model, other IX models, for example, a particle-diffusion model, also give an "S" shaped curve for effluent concentration versus volume. In fact, it would be expected that a particle-diffusion model would be more accurate than a liquid-film model as exhaustion nears completion because the resin is nearly at equilibrium with the exhausting solution and the concentration driving force across the liquid film becomes small relative to concentration differences within the resin beads. There are only slight differences in the particular shapes of the "S" curves of many of the various possible models, and these shapes are difficult to differentiate between relative to the error of ion-exchange experiments. Thus, just because a given set of IX data can be fit reasonably by equation 22 or 23 does not prove in itself that the liquid-film model is the true physical description of the IX-transport behavior [29].

Results. – Exhaustion-effluent concentration data from the laboratory experiments given in appendix F were fit to the liquid-film model. Regression analyses of ln C/C_0 of calcium, magnesium, and total hardness (calcium plus magnesium) as dependent variables and V (exhaustion throughput volume) were performed to fit equation 22. Computer printouts and plots of some of the regression analyses are given in appendix H. A typical semilog plot for calcium of cycle 1.01.06 is given on figure 8, which contains the same data as on figure 6. The three data points lying in nearly a straight line were selected from the plot on figure 8 for the regression analysis, resulting in the straight-line fit. These three data points occur in the range of resin breakthrough of calcium, which is the range of applicability of the liquid-film model. Points before the three are initial leakage. Points after the three are final approach to equilibrium between the exhausting solution and resin where particle diffusion can be expected as an influencing transport mechanism. Similar plots for magnesium and total hardness concentrations did not yield such straight lines, which could be due to poor precision of the chemical analysis method used for total hardness. (Magnesium concentration was calculated as the difference between total hardness and calcium concentrations, each determined by titration where a colorimetric end point must be visually detected.)

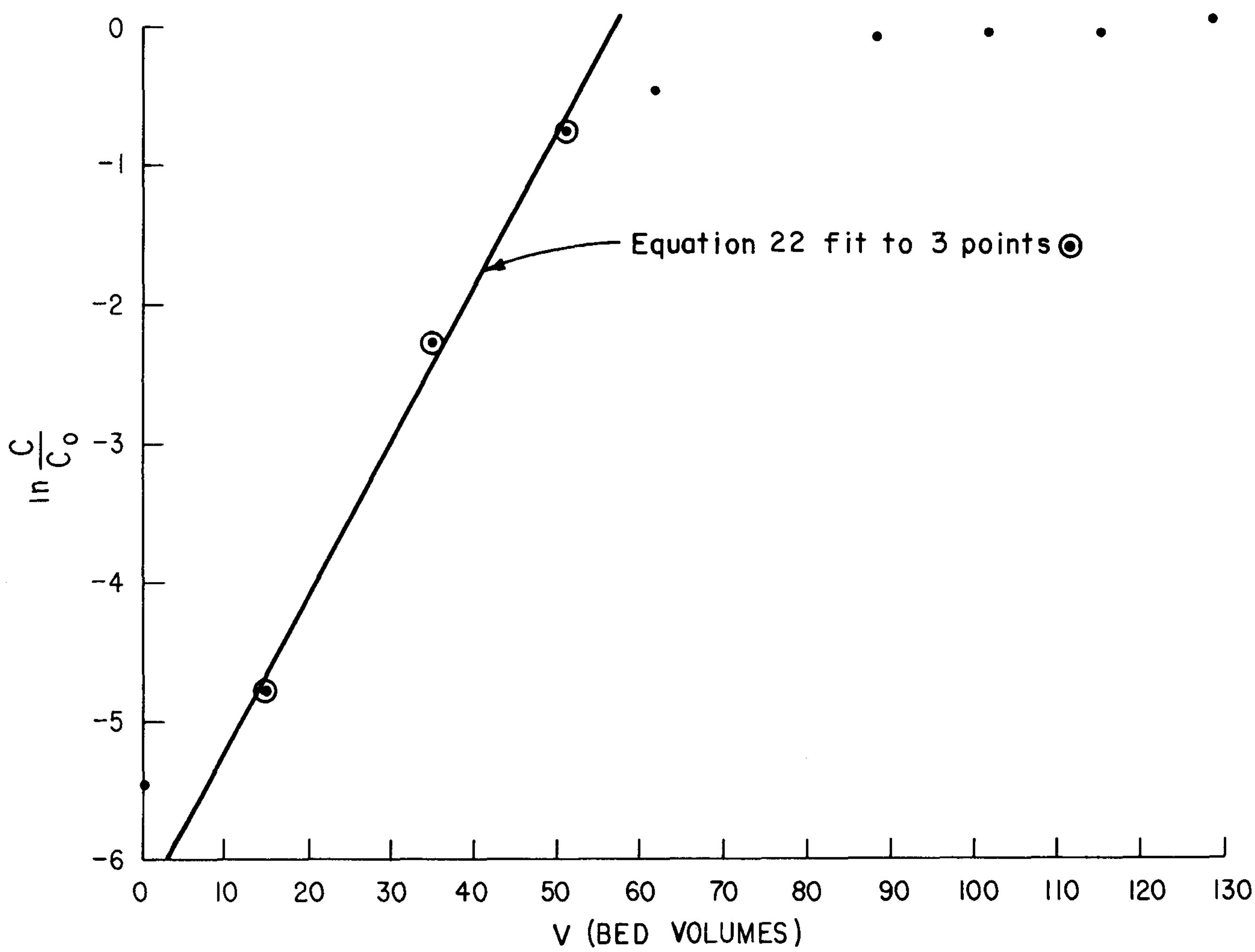

Figure 8. – Semilog plot of calcium effluent concentration ratio versus effluent volume for cycle 1.01.06.

Table 10 is a summary of the regression information for the liquid-film model for calcium (equation 21) in each cycle. Table 10 shows the values of the apparent k_L and a calculated from the slope and intercept. The adjective "apparent" is used here because successful straight-line fits of the semilogarithmic plots do not in themselves prove the validity of the liquid-film model given by equation 22 because other mechanisms also could give such a fit. The assumptions used in developing equation 22 are not entirely in force with the present laboratory data as noted earlier in this section. Assuming the validity of equation 22, a may be considered the net equilibrium specific resin capacity for calcium, which is the difference between the equilibrium q_{Ca}'s for the regeneration and the exhaustion feed solutions.

In addition to C/C_o regression analysis also were performed and plots were made for calcium, magnesium, and total hardness on ln $[(C-C_e)/(C_i-C_e)]$ versus V to try to fit the exhaustion effluent concentration data to equation 23, the other form of the liquid-film model that was developed, because it would be presumably more accurate than equation 22. It was found that the data fit by equation 23 did not fit well with a straight line. A sample plot for calcium is on figure 9 using the same data as on figure 8. For all the cycles, the best fit of the data using this latter concentration function would have been a convex curve of the shape indicated by the three points about the straight line on figure 9. Analysis of the data for magnesium and total hardness using this same method gave similar unsatisfactory results.

Thus, although equation 22 does not appear to be as rigorous theoretically as equation 23, the plots of C/C_o for calcium versus V as indicated by equation 22 gave straight line fits, which were highly significant statistically, for all of the laboratory IX cycles. Similar plots as on figure 9 did not fit equation 23. Because of the success of the semilog form of equation 22 to fit the data, equation 22 was tentatively selected as a useful description of calcium breakthrough. Equation 21 was rewritten in terms of C/C_o:

$$\frac{C}{C_o} = \exp\left(\frac{k_L\, C_o}{aG_e}\; V - \frac{k_L\, V_{resin}}{G_e} - 1\right) \qquad (24)$$

where exp ( ) means that the value within the parentheses is the exponent of e, the base of natural logarithms.

Using the values from curve-fitting in table 10 for cycle 1.01.06 and equation 24, values for C/C_o were calculated as a function of V; the values are shown plotted on figure 10. Note that equation 24 provides a good fit of the experimental data during the initial breakthrough of calcium where liquid-film mass transfer resistance would be expected to dominate. The relatively greater deviation of the curve from the forth data point at 50 bed volumes relative to the second and third points is due to the exponential transformation of the least-squares fit parameters obtained from ln C/C_o versus V. Nonlinear regression methods would produce a more equal fit of each of the untransformed data points. Beyond the half-height point the exponential equation does not fit the data adequately, which is also where particle-diffusion control is expected to begin to dominate as total exhaustion is approached. Note that the practical breakthrough concentrations of 6 and 12 meq/L of calcium, where exhaustion was terminated in the LVS field experiments, lie in the range where equation 24 fits the data well.

Table 10. – *Values from linear regression fit of laboratory IX data ln C/C_o of calcium versus V, exhaustion-throughput volume in bed volumes (1 bed volume = 500 mL), apparent mass-transfer coefficients, k_L, and total calcium resin capacities, a, of liquid-film model*

Cycle number	Number data points	Semilog slope BV^{-1}	Standard error of slope	Semilog intercept	Standard error of intercept	k_L, $second^{-1}$	a, eq/L
1.01.01A	4	0.0852	0.010	– 6.30	0.39	0.122	1.356
1.01.01B	4	.0738	.005	– 4.42	.26	.0806	1.124
1.01.02X	4	.0929	.005	– 6.46	.23	.1213	1.335
1.01.02B	3	.173	.005	– 7.43	.20	.1439	1.565
1.01.03	3	.0858	.005	– 5.65	.30	.0484	1.453
1.01.04	3	.0912	.002	– 4.76	.03	.0383	0.955
1.01.05	3	.141	.005	– 4.72	.08	.0387	1.056
1.01.06	3	.113	.010	– 6.29	.30	.1164	1.096
1.01.07	2	.132	0*	– 4.05	0*	.0671	0.961
1.01.08	4	.149	.002	– 5.23	.04	.0419	1.145
1.02.01	5	.163	.010	–11.61	.52	.157	1.459

* Because there were only two data points within the appropriate range for cycle 1.01.07, the first order curve fit passed exactly through the two points and had no residual error.

On figure 10, the double mirror image of the exponential function rotated about the half height is the short dashed line, which is plotted to show how the "S" shaped curve could appear if it were symmetrical. The deviation of this short dashed curve from the longer dashed curve drawn to pass through the experimental data shows clearly that the experimental "S" shaped curve is not symetrical. This general type "S" shape of the experimental data, where the bottom of the "S" has more curvature than the top, is indictive of particle-diffusion controlled mass transfer in the later portion of the exhaustion breakthrough [29].

The various areas marked A through E on figure 10 are used to describe the differences among various estimates for specific calcium resin capacity q_{Ca}. Multiplication of a measured area (dimensionless on figure 10) by the feed-water calcium concentration yields an estimate of q_{Ca}. The different estimates of q_{Ca} for each experimental cycle are given in table 7. The experimental estimate of the amount of calcium removed per IX cycle (table 7, column 3) corresponds to the entire area B+C+D+E. It was estimated in the present work using the trapezoidal method of numerical integration. In the present discussion, this experimental value is considered the "true value" for comparison with the other estimates, which are greater approximations, but of course, it is subject to experimental error.

The *a* of the liquid-film model — an estimate of q_{Ca} contained in equation 22 — is represented by the area B+C. Because the area is but a portion of the true area, it is easy to see why it is a lower estimate of each q_{Ca} (table 7, column 5) than the experimental value.

The half-height estimate of q_{Ca}, represented by the rectangular area A+B+C on figure 10, is the bed volumes at $C/C_o = 0.5$ times the influent calcium concentration. It is used sometimes because it can be simple to calculate and is easy to describe theoretically. In the last column of table 7, the half-height estimates are also less than the experimental estimates, and would only be equal to the true value if the "S" curve were symmetrical, as the double-mirror-image curve of the exponential function

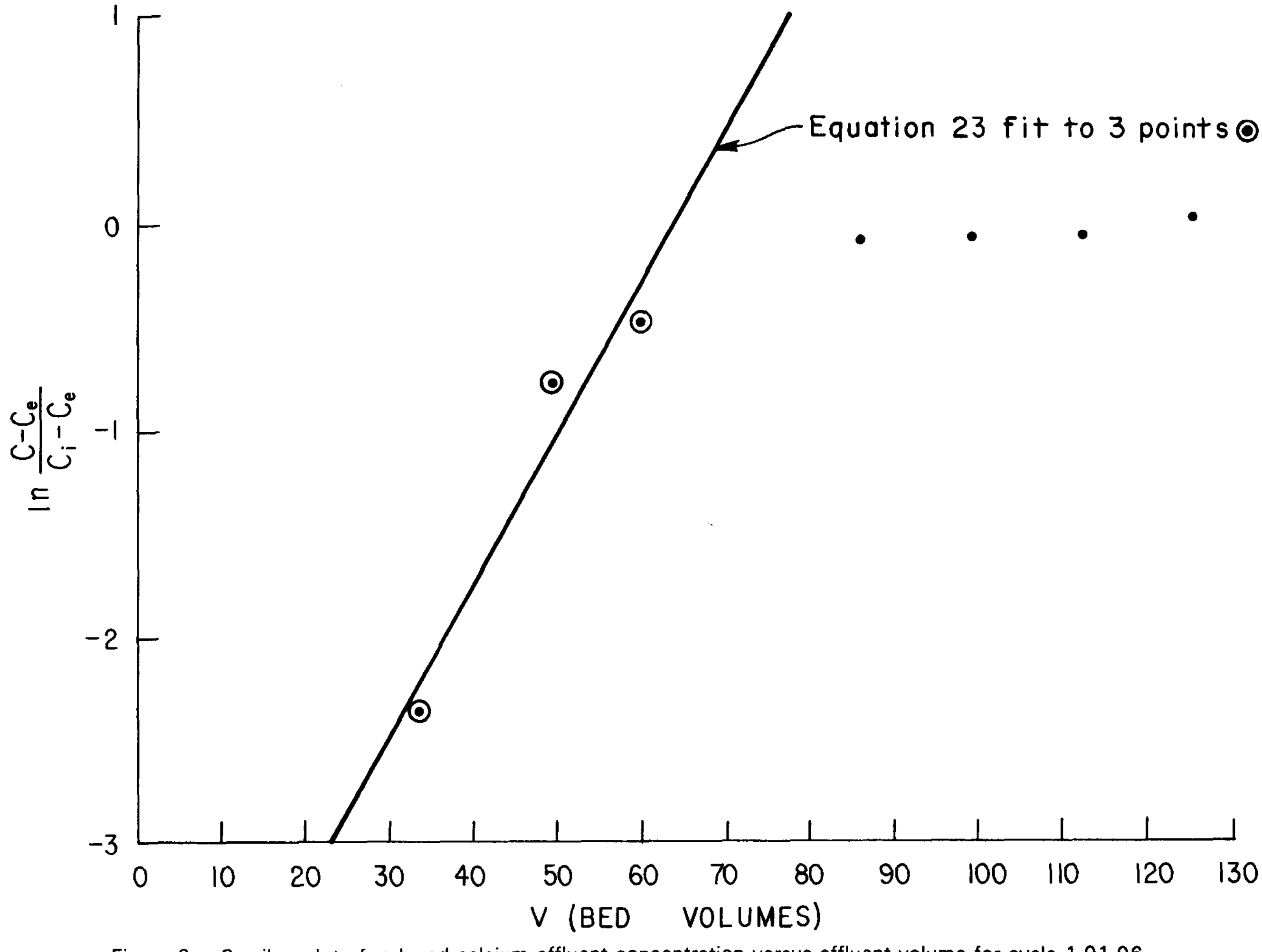

Figure 9. – Semilog plot of reduced calcium effluent concentration versus effluent volume for cycle 1.01.06.

shown as the short dashed curve on figure 10, or where the areas A=C+D.

Thus, none of the other three methods of estimating q_{Ca} in table 7 appear to be an accurate substitute for the experimental value obtained by trapezoidal integration. All three gave low estimates with the present data. However, these other methods may be useful for providing quick, rough estimates, depending upon the accuracy required, because they may be easier to calculate and require fewer data points.

Regression analysis was performed on the combined summary data from the various cycles with the apparent k_L and a as the dependent variables. Independent variables in the regressions included all the control variables in the laboratory IX experiments, namely, exhaustion-feed and regenerant water compositions, water temperature, and exhaustion flow rate. Regeneration flow rate was not included because it will not affect exhaustion when the regeneration is totally to equilibrium. These regressions were done for possible prediction of the location and slope of the calcium-breakthrough curve as a function of different IX operating conditions. Computer printouts from these regressions are in appendix H.

Results of these regressions with k_L as the dependent variable were that only the exhaustion flow rate G_e of all the control variables had a statistically significant relation with k_L. This would be expected in the liquid-film model, although a weak relation with water temperature had been observed [33]. Note that the water compositions in the laboratory experiments did not relate significantly (using the partial F test [25] and 95 percent confidence limits) to k_L, although they did relate significantly with a as described in the following paragraph. The equation form selected between k_L and V was a power model because it is often used for mass-transfer coefficients and can give a good fit with only two parameters. Moreover, because only two levels of G_e were controlled in the experiments, it would not be possible to detect curvature and to differentiate

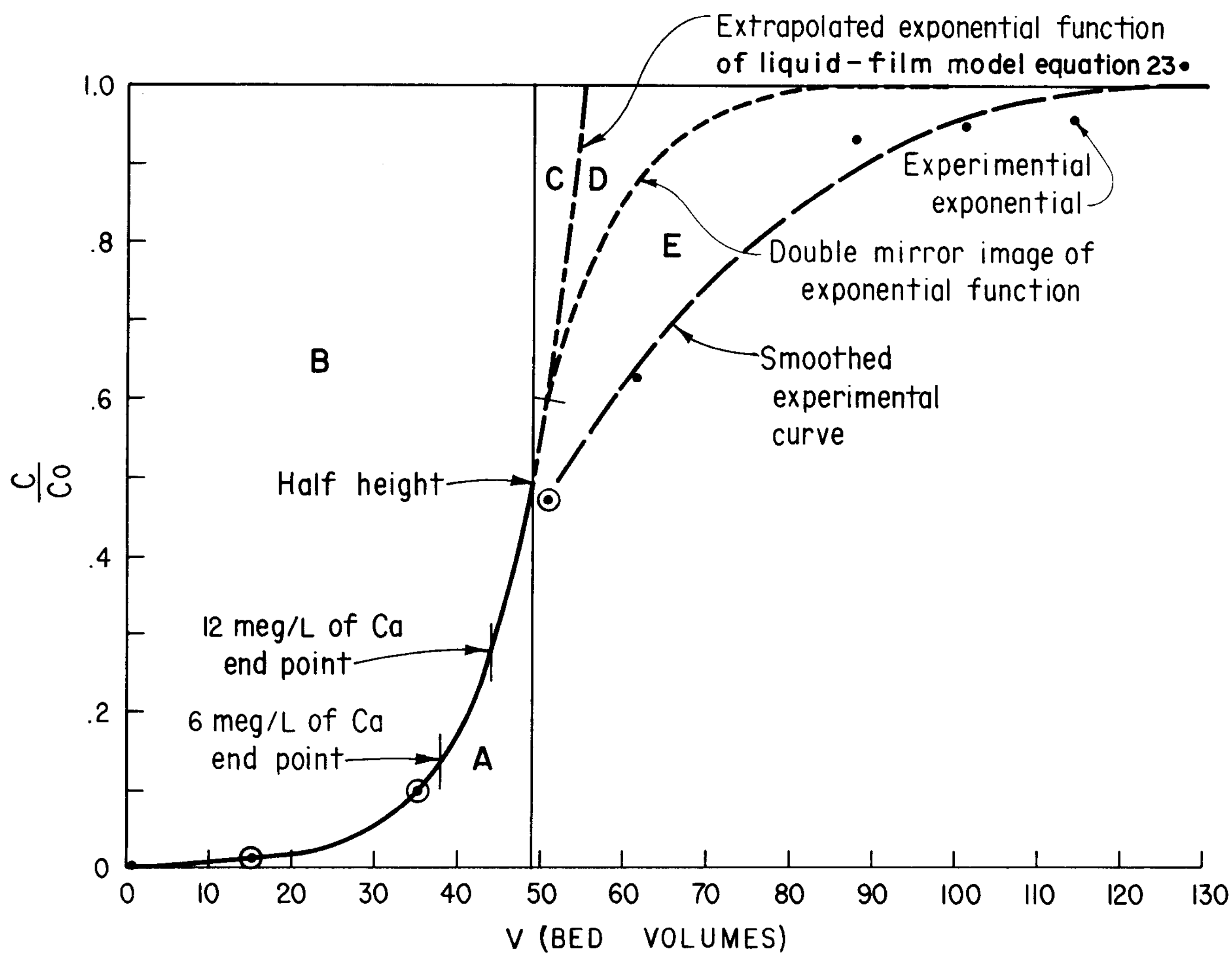

Figure 10. – Fit of liquid-film model to calcium effluent concentrations during cycle 1.01.06, areas of different estimates of specific resin capacity also are shown.

between the various possible functions of k_L versus G_e with the data. The resulting regression equation for k_L is:

$$k_L = 0.00281 \ v^{1.17} \qquad (25)$$

where v is the superficial flow velocity (mm/s) which is the volumetric flow rate G_e divided by the resin-bed cross-sectional area.

Equation 25 contains v in place of G_e to make it more generally applicable for resin beds of any cross-sectional area containing DOWEX®HCR-W2 resin and operating with comparable conditions and water compositions. The log-log plot of k_L versus v containing the regression line of equation 25 and the experimental data are given on figure 11. The 95-percent confidence limits for the 1.17 exponent in equation 25 are relatively wide at 0.71 to 1.62. For liquid-film mass-transfer, this exponent should be less than 1 [29], for example, about 0.7 according to one article [33] and 0.5 according to another [30]. Thus, within the experimental variability and the goodness of fit of the model, equation 25 is consistent with many of the results of others.

Multiple regression analysis of a as the dependent variable showed that the only control variables significantly affecting it were the exhaustion-feed and regenerant compositions. This finding is consistent with the previous discussion regarding the equilibrium model for estimating q_{Ca}. None of the data from the regressions fitting a are given here because the

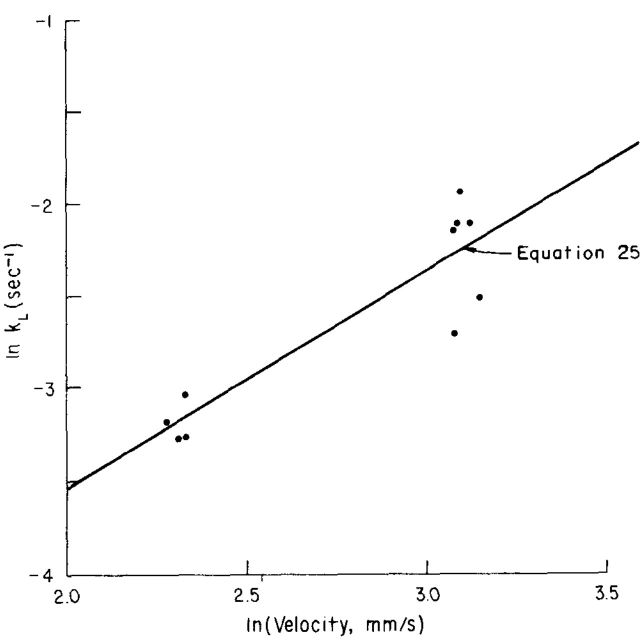

Figure 11. – Log of liquid-film mass-transfer coefficient versus log of superficial velocity of exhaustion flow.

equilibrium model given earlier in this section provides a more accurate and meaningful estimate of q_{Ca}.

Limited regression analysis was performed on the LVS field data using the liquid-film model. The results, not included in this report, were not as encouraging as with the laboratory data because the apparent k_L varied with regenerant composition when exhaustion-flow rate was held constant. If the liquid-film model were valid, k_L should be independent of ionic water composition, as was observed in the laboratory experiments. The calculated a values were also about one-half of the values that would be expected based on other estimates of q_{Ca}. The reasons for the poor fit of the model to the field data are not entirely clear, but the fact that the exhaustion steps of the field experiments were run to breakthrough calcium concentrations of 6 and 12 meq/L rather than to equilibrium as in the laboratory experiments, limited the range of the exhaustion-effluent calcium-concentration data for curve fitting (see fig. 9). It is also true that the regenerations were not done to ionic equilibrium between resin and regenerant at LVS as in the laboratory experiments, which certainly could affect the subsequent exhaustion breakthrough curves.

In summary, the liquid-film model gives a good fit of the laboratory data including separation of flow-rate and solution composition affects into two separate parameters, k_L and a, which have apparent physical meaning according to the model. Thus, considerable progress has been made in developing a predictive model for the exhaustion step of an IX cycle. Less success was achieved in fitting the liquid-film model to the LVS field experiments, but the field experiments were not designed for obtaining the data needed to test the liquid-film model. Additional field experiments would be required with this goal in mind.

Modeling the Regeneration Step

Development of equations to describe the dynamic behavior of the cation exchange between regenerant and IX resin was beyond the scope of the present phase of study. The equilibrium model presented early in this section described the resin capacity at equilibrium with influent solutions. This equilibrium model did not account for a limited regeneration volume nor for the rate of exchange between solution and resin. Some information on a regeneration model was gathered in the course of the literature review needed to develop the models contained previously in this section. This information can be used as a starting point to develop a regeneration model in the future.

The importance of mathematically describing the regeneration step is that the efficiency of using the regeneration solution and the concentration profile within the resin bed at the beginning of exhaustion can be described. Both have an effect on the exhaustion, and thus, cycle performance. A nonuniform concentration profile in the bed at the end of incomplete regeneration becomes an initial boundary condition for the exhaustion model. The stoichiometric efficiency of using the chemicals in the regenerant solution to regenerate the resin can be substantially less than 1.0 in strong acid cation exchange (the present system), and a regeneration model should predict the inefficiency.

At the high normalities of regenerant solutions, the mass-transfer resistance between solution and resin is usually relatively small relative to the equilibrium dynamics between solution and resin bed [29]. The equilibrium between solution and resin is probably unfavorable in the regeneration exchange of regenerant sodium for calcium on the HCR-W2 resin. Mathematically, the right side of equation 9 will be greater than 1.0 if equilibrium is unfavorable. According to equation 9 if C_o^* were high enough this exchange equilibrium would be favorable, but this probably does not occur in the present system under study. Unfavorable equilibrium results in a proportional concentration profile, one in which the calcium eluting peak tends to spread out with increasing time and axial distance through the resin. This proportional profile contrasts with the favorable equilibrium case of exhaustion (liquid-film model) where the exchange front is "self-sharpening." The mathematics of the proportional pattern predict the effluent history of regeneration from solution IX resin equilibrium and mass-balance relationships. Only a minor correction may be needed to account for the mass-transfer resistance. Thus, previous work in the scientific literature [27 to 31] provides a basis with which a regeneration model could be developed as an extension of the present study. This would result in a more accurate model for predicting the performance of the entire IX cycle where limited regeneration volume and less than ideal regenerant-brine compositions strongly affect the IX performance.

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APPENDIX A

DOWEX® HCR-W2 Specification Sheet

ION ± EXCHANGE

applications • recommendations • materials

T.D. Index 120.04

DOWEX HCR-W2 cation exchange resin

A second generation premium quality resin—DOWEX* HCR-W2 cation exchange resin—is produced by a new improved process. It replaces DOWEX HCR-W resin in all applications requiring superior physical stability and closely graded particle sizing. The excellent operating characteristics and outstanding physical stability which made DOWEX HCR-W resin the standard of excellence during the past 15 years are maintained. In fact, the new manufacturing process provides an even higher degree of physical stability as measured by friability tests now standard in many specifications.DOWEX HCR-W2 is more closely screened than standard water treatment resins. It is supplied to meet tight 16/40 mesh specifications typical for condensate polishing and other high flow rate applications.

APPLICATIONS

Industrial and municipal water softening—DOWEX HCR-W2 resin is recommended for use in hot or cold zeolite softeners. It stays clean, resists breakdown and performs with a minimum of resin loss. It is especially well suited for upflow open-type municipal water softeners, assuring a minimum of particles leaving the system.

Deionizing—Mixed beds containing DOWEX HCR-W2 resin have lower pressure drop and are easily separated and regenerated. Freedom from fines formation assures maximum water quality and operation at design conditions for longer periods than similar beds of standard resins.

Continuous systems—Physical stability is extremely important in this kind of service. DOWEX HCR-W2 resin can be used alone or with a DOWEX anion resin in softening and other continuous ion exchange processes. Resistance to osmotic shock adds to its value as a superior cation exchanger for this service. Compatible with most anion resins, mixed moving beds are used with greatest safety to physical life of the anion resin.

High flow rate condensate polishing—This application owes much of its success to the marked physical stability of DOWEX HCR-W resin. DOWEX HCR-W2 resin exhibits an even higher degree of uniformity when measuring physical stability by acceptable procedures, and it carries friability specifications equal to or exceeding most requirements. It is our unrestricted judgment that DOWEX HCR-W2 resin may be used without reservation for all condensate polishing systems without reference to special particle sizing to assure optimum water quality and lowest pressure drop since it is supplied to meet industry 16/40 mesh specifications. Superior physical stability, which practically eliminates bead breakage and formation of fines due to external regeneration or high flow operations, insures low pressure loss and high capacity cycle after cycle.

DOW CHEMICAL U.S.A.
AN OPERATING UNIT OF THE DOW CHEMICAL COMPANY
FUNCTIONAL PRODUCTS AND SYSTEMS DEPARTMENT
MIDLAND, MICHIGAN 48640

Physical and Chemical Properties

Physical Form	Hard, spherical beads.	
Sphericity — Original	95% Min.	
	Na^+ Form	H^+ Form
Water Retention Capacity	44-48%	51-54%
Shipping Weight lbs./cu. ft.	53	50
Minimum Capacity		
meq/g dry resin ...	4.4	4.8
meq/ml wet resin .	2.0	1.8
Kgr/cu. ft. as calcium carbonate	43.6	39.2
Color Throw, APHA No	20	40
Specific Gravity	1.28	1.21
Friability — gm/bead minimum for 95% of beads	>200	>200
average	>350	>350
Standard Screen Size (Wet)		
on 16 mesh	2% max.	2% max.
Through 40 mesh ..	1% max.	1% max.
Screen Index Range ..	300-450	300-450

Suggested Operating Conditions

pH Range	0-14
Maximum Temperature	300°F
Minimum Bed Depth ..	30 inches
Service Flow Rate	2-4 gpm/cu. ft.
Back Wash Flow Rate .	7-8 gpm/sq. ft. at 77°F (See Fig. 1)

DOWEX HCR-W2 cation exchange resin meets the requirements of Food Additive Regulation 121.1148. (Now Title 21, Subpart A, 173.25.)

PHYSICAL AND CHEMICAL PROPERTIES

Physical stability — The superior physical stability of DOWEX HCR-W resin has long been established as a standard of the high performance ion exchange industry. The new manufacturing process for DOWEX HCR-W2 resin eliminates cracks and weak spots within the resin beads. This superior stability permits use under severe conditions, such as high flow rates.

Hydraulic characteristics — Particle size of DOWEX HCR-W2 resin is specifically controlled in manufacture, resulting in excellent hydraulic properties. (See Figures 1 and 2). The compression caused by high flow rates, attrition in backwash, and osmotic shock in saturated brine and strong acid regenerants, have a minimum effect on the resins' performance and efficiency.

High capacity — Exceptionally high capacity has been built into DOWEX HCR-W2 resin. Correspondingly high regeneration efficiency is obtained and resin loss due to bead fracture is minimized.

FIGURE 1 — Expansion Characteristics of DOWEX HCR-W2 Resin

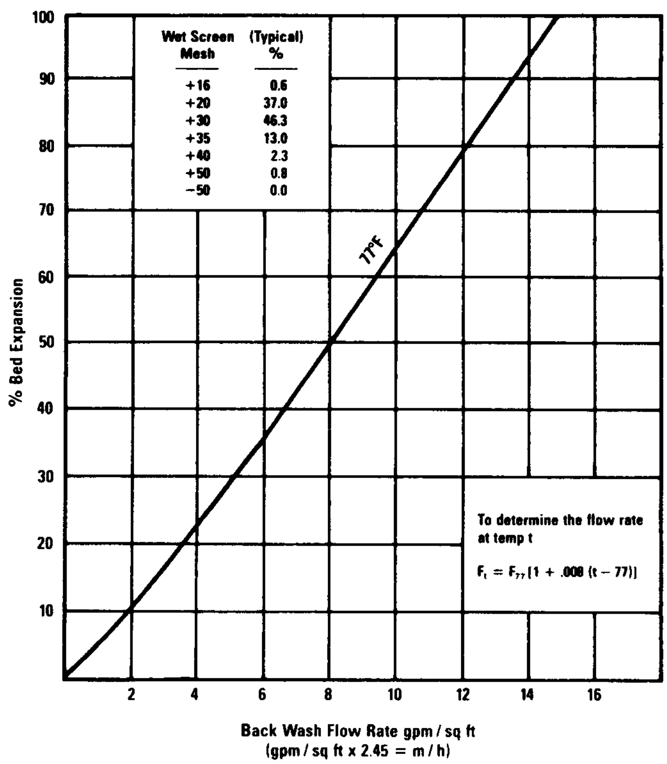
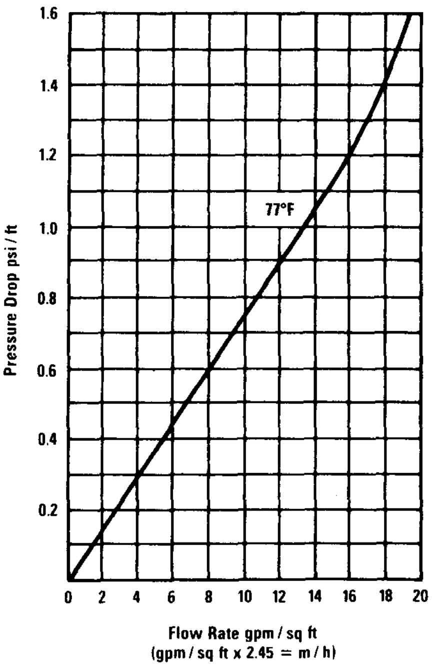


FIGURE 2—Pressure Drop with DOWEX HCR-W2 Resin



Wet Screen Mesh	(Typical) %
+16	0.6
+20	37.0
+30	46.3
+35	13.0
+40	2.3
+50	0.8
−50	0.0

To Find Pressure Drop at other Temperatures, Multiply Pressure Drop at 77°F by Factor

t(°F)	Factor
35	1.89
45	1.59
55	1.35
65	1.17
90	0.86
120	0.63

Sodium Cycle Operation:

Regenerant Level	Dependent on leakage and capacity desired (see Fig. 3 & 4)
Regenerant Concentration	10-26% NaCl
Regenerant Transfer Time	2 min. / lb. NaCl / cu. ft.
Rinse Water Requirement	20-40 gal. / cu. ft.
Displacement Rinse Rate	Adjusted to insure 30 min. contact with NaCl
Final Rinse Rate	Equal to service rate

FIGURE 3— Softening Capacity of DOWEX HCR-W2 Resin

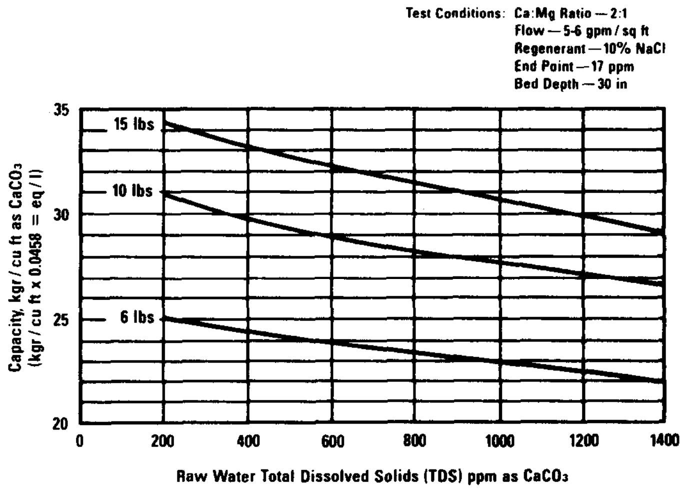
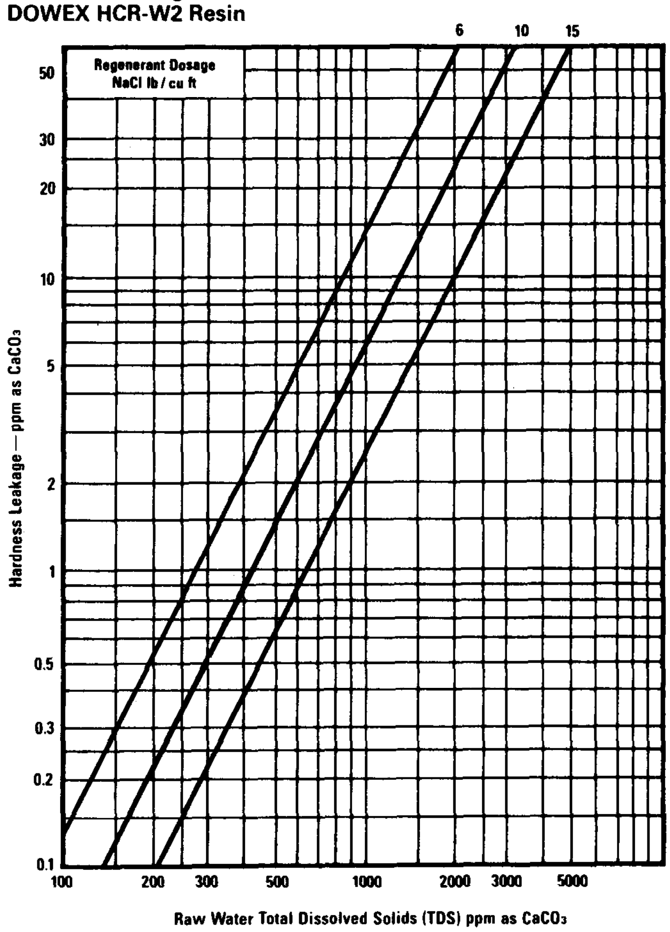


FIGURE 4—Sodium Cycle / Operation Hardness Leakage DOWEX HCR-W2 Resin



Hydrogen Cycle Operation:

Regenerant Level	Dependent on leakage and capacity desired (see Figs. 5 and 6)
Regenerant Concentration	4-10% HCl 2-8% H_2SO_4
Regenerant Flow Rate	0.5-2.0 gpm/cu. ft.
Rinse Water Requirement	40-100 gals./cu. ft.
Displacement Rinse Rate	Equal to regenerant rate
Final Rinse Rate	Equal to service rate

FIGURE 5—Capacity of DOWEX HCR-W2 Resin in Hydrogen Cycle—HCl Regeneration

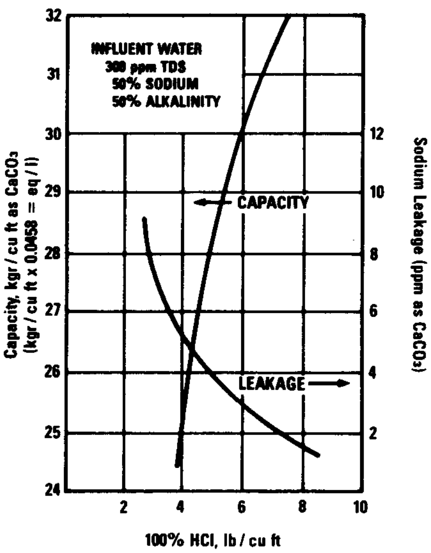


FIGURE 6—Capacity of DOWEX HCR-W2 Resin in Hydrogen Cycle—H_2SO_4 Regeneration

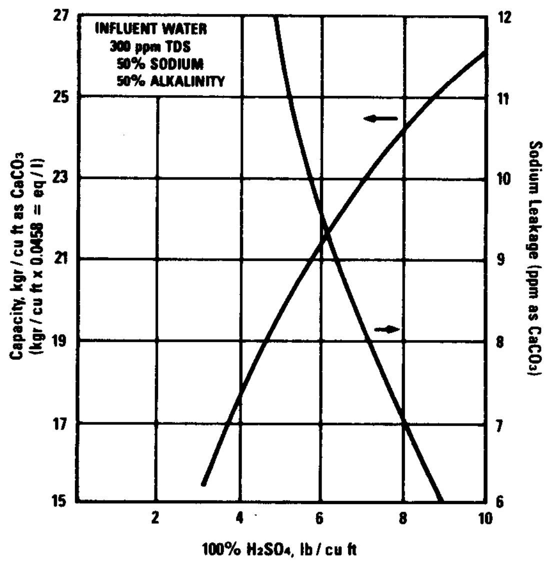
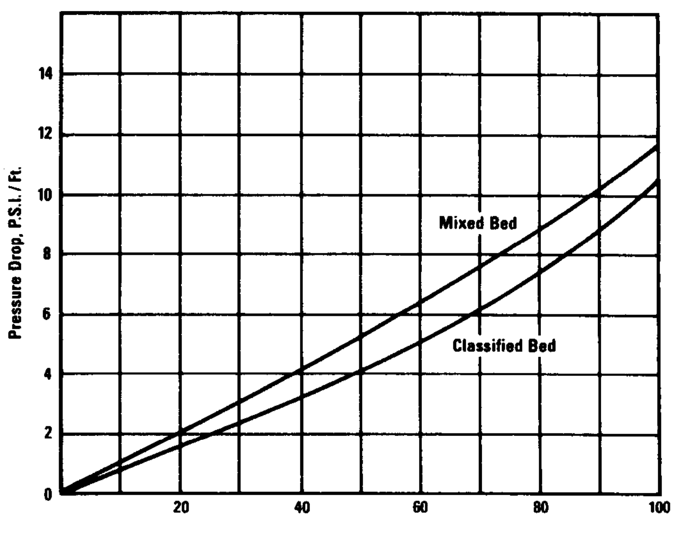


FIGURE 7—Pressure Losses Through DOWEX HCR-W2 DOWEX SBR•P Resin in Mixed Bed and Classified Bed



DOW CHEMICAL U.S.A.
AN OPERATING UNIT OF THE DOW CHEMICAL COMPANY
FUNCTIONAL PRODUCTS AND SYSTEMS DEPARTMENT
MIDLAND, MICHIGAN 48640

APPENDIX B

LVS Field IX Data

Ion-Exchange - Run L.01.00

Date:	1/29/80		
Cycle:	L.01.97		
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - Fresh ED Brine Source of backwash - IX feedwater		
		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS-calc.)	-	41 100
	Fresh regeneration conc. (mg/L TDS-evap.)	-	41 300
	Fresh regeneration flow rate (L/min)	12.0	12.1
	Recycled regenerant flow rate (L/min)	None	None
	Recycled regenerant volume (L)	None	None
	Service termination point (meq/L Ca^{++})	12.0	12.8
	Heat exchanger used	No	No
	Packed bed regeneration mode used (i.e., resin hold-down)	No	No
Standard resin bed:	Height[a] = 1 128 mm Volume = 103.0 L		

Chemical Compositions of Tank Waters (Prior to Cycle) L.01.97

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	7.3	3 570	97.0	54.0	151.0
Lime-softened feed (T-9)	7.3	1 100	23.8	9.4	33.2
Lime-softened feed (T-10)	7.1	1 080	22.4	10.6	33.0
Fresh ED brine (T-28)	6.6	4 170	18.0	20.4	38.4
IX product/ED feed (T-33)	7.2	1 150	3.9	4.9	8.8
Lime-softened feed (clearwell)	7.3	1 100	23.2	10.6	33.8

[a]The standard resin bed height was determined by measuring the height of the resin at the end of the drain-down after regeneration with fresh ED brine.

OPERATING CONDITIONS

CYCLE L.01.97

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	263	2.55	26.3	.255	39.	23.5
DRAIN 1	(VENT)	WASTE	5	68	.66	13.7	.133	0.0	
REGEN 3	FR REGEN	SP REGEN	62	749	7.27	12.1	.117	19.	15.5
DRAIN 2	(VENT)	WASTE	5	68	.66	13.7	.133	0.0	
RINSE	FEED	WASTE	10	155	1.50	15.5	.150	0.0	
SERVICE	FEED	PRODUCT	120	3560	34.6	29.7	.288	0.0	
DRAIN 3	(VENT)	WASTE	4	55	.53	13.7	.133	0.0	
			216						

Fresh Regenerant Volume Balance

Cycle L.01.97

Run L.01.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
19	1/15/80	240	-	1 920	-	80	0.62
20	1/15/80	300	-	2 240	-	80	0.67
21	1/15/80	610	-	2 920	-	80	1.04
22	1/15/80	600	-	2 840	-	80	1.06
23	1/16/80	600	-	3 030	-	80	0.99
24	1/16/80	607	-	3 270	-	80	0.93
25	1/16/80	617	-	3 150	-	80	0.98
26	1/16/80	599	-	3 000	-	80	1.00
27	1/17/80	600	-	2 900	-	80	1.03
28	1/17/80	592	-	2 730	-	80	1.08
29	1/17/80	615	-	2 680	-	80	1.15
30	1/17/80	600	-	3 280	-	80	0.91
34	1/18/80	606	-	3 220	-	80	0.94
35	1/18/80	588	-	3 390	-	80	0.87
36	1/18/80	606	-	3 200	-	80	0.95
37	1/19/80	609	-	3 170	-	80	0.96
38	1/19/80	597	-	3 170	-	80	0.94
39	1/19/80	594	-	3 240	-	80	0.92
40	1/19/80	600	-	3 330	-	80	0.90
41	1/19/80	682	-	3 330	-	80	1.02
42	1/19/80	681	-	3 380	-	80	1.00
47	1/20/80	680	-	3 560	-	80	0.96
48	1/20/80	682	-	3 900	-	80	0.87
49	1/21/80	679	-	3 520	-	80	0.96
50	1/21/80	680	-	3 330	-	80	1.02
51	1/21/80	681	-	3 170	-	80	1.07
52	1/21/80	678	-	3 270	-	80	1.04
53	1/21/80	677	-	3 270	-	80	1.04
54	1/21/80	677	-	3 550	-	80	0.95
55	1/22/80	675	-	3 250	-	80	1.04
56	1/22/80	677	-	3 250	-	80	1.04
57	1/22/80	675	-	3 150	-	80	1.07
64	1/23/80	680	-	3 870	-	80	0.88
65	1/23/80	680	-	3 830	-	80	0.89
66	1/23/80	681	-	3 870	-	80	0.88
67	1/24/80	680	40 603	3 930	9 893	80	0.87
68	1/24/80	679	40 603	3 840	9 893	80	0.88
69	1/24/80	556	40 603	3 420	9 893	80	0.81
80	1/24/80	860	40 603	3 940	9 893	80	1.09
71	1/24/80	857	40 603	3 680	9 893	80	1.16
72	1/25/80	858	42 000	3 820	13 000	80	1.12
73	1/25/80	852	42 000	3 820	13 000	80	1.12
74	1/25/80	750	42 000	3 500	13 000	80	1.07
75	1/25/80	747	42 000	3 540	13 000	80	1.06
76	1/25/80	750	42 000	3 600	13 000	80	1.04

Cycle L.01.97 (concluded)

Run L.01.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_s) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_s$
82	1/26/80	753	-	3 760	-	80	1.00
83	1/27/80	748	-	3 490	-	80	1.07
84	1/27/80	750	-	3 500	-	80	1.07
85	1/27/80	752	-	3 670	-	80	1.02
86	1/27/80	752	-	3 590	-	80	1.05
87	1/27/80	750	-	3 640	-	80	1.03
88	1/27/80	751	-	3 450	-	80	1.09
89	1/27/80	750	-	3 390	-	80	1.11
90	1/28/80	753	41 570	3 540	8 960	80	1.06
91	1/28/80	750	41 570	3 540	8 960	80	1.06
92	1/28/80	752	41 570	3 550	8 960	80	1.06
93	1/28/80	749	41 570	3 350	8 960	80	1.18
94	1/28/80	400	41 570	2 490	8 960	80	0.80
95	1/29/80	750	-	3 430	-	80	1.09
96	1/29/80	754	-	3 460	-	80	1.09
97	1/29/80	749	-	3 560	-	80	1.05

Influent and Effluent Compositions during IX Regeneration and Service - Cycle L.01.97
(All samples composites except regeneration influent)
(Analyzed at Boulder City on 3/10/80)

	Units	Regeneration Influent	Regeneration Effluent [a]	Rinse & service influent	Service effluent
pH	units	7.6	-	7.7	7.8
TDS (calculated)	mg/L	38 500	39 700	8 680	8 760
TDS (evaporated @ 180°C)	mg/L	39 100	38 800	8 570	8 590
Conductivity @ 25°C	mS/m	4 860	-	1 250	1 300
Silica	mg/L	15	0	15	15
Calcium	mg/L	380	2 320	440	105
Magnesium	mg/L	256	659	137	70.2
Sodium	mg/L	12 500	10 500	2 310	2 800
Potassium	mg/L	1 210	860	205	284
Iron, total	mg/L	0.27	0	0.05	0
Manganese, total	mg/L	0.11	<0.4	0.05	0.05
Strontium	mg/L	5.5	30	6.3	1.5
Bicarbonate	mg/L	78.7	104	41.5	40.9
Carbonate	mg/L	0	0	0	0
Hydroxide	mg/L	-	-	-	-
Sulfate	mg/L	8 640	9 600	2 000	2 020
Chloride	mg/L	15 500	15 700	3 540	3 440
T-alkalinity as $CaCO_3$	mg/L	65	90	34	34
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0
T-phosphorus as PO_4	mg/L	0.7	0	1.0	0.9
E.F. [TDS(calculated)/cond.]		7.9	-	6.9	6.7
E.F. [TDS(evaporated)/cond.]		8.0	-	6.9	6.6
Σ Anions	meq/L	616.6	643.9	142.1	139.7
Σ Cations	meq/L	615.0	648.0	139.7	139.8
Control value	meq/L	+0.17	-0.41	+1.04	-0.04

[a] The BW/RG-E sample was inadvertently excluded in the composite.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.01.97

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	22.95	14.81	37.77	109.61
BACKWASH	EFFLUENT	1.28	21.21	12.84	34.05	101.35
REGEN 3	EFFLUENT[a]	2.55	29.94	20.08	50.02	105.26
REGEN 3	INFLUENT	3.38	18.96	21.07	40.03	543.71
REGEN 3	EFFLUENT[a]	4.43	154.69	80.33	235.02	392.78
REGEN 3	EFFLUENT[a]	6.31	117.27	52.76	170.02	452.37
REGEN 3	EFFLUENT[a]	8.19	84.83	42.72	127.55	500.22
REGEN 3	EFFLUENT[a]	9.84	72.36	40.16	112.52	461.07
RINSE	EFFLUENT	0.00	40.92	28.15	69.07	53.50
RINSE	EFFLUENT	.75	11.98	7.03	19.00	215.31
RINSE	EFFLUENT	1.50	3.24	2.01	5.25	134.41
SERVICE	EFFLUENT	1.50	3.24	2.01	5.25	136.15
SERVICE	INFLUENT	3.52	21.71	11.03	32.74	100.04
SERVICE	EFFLUENT	5.83	3.24	2.01	5.25	129.19
SERVICE	INFLUENT	17.06	21.46	10.53	31.99	99.61
SERVICE	EFFLUENT	19.07	2.99	2.01	5.00	126.14
SERVICE	EFFLUENT	27.72	4.24	6.53	10.77	119.62
SERVICE	EFFLUENT	32.04	9.23	14.32	23.55	109.61
SERVICE	INFLUENT	36.07	21.46	10.78	32.24	103.96
SERVICE	EFFLUENT	36.07	12.72	16.05	28.77	107.00

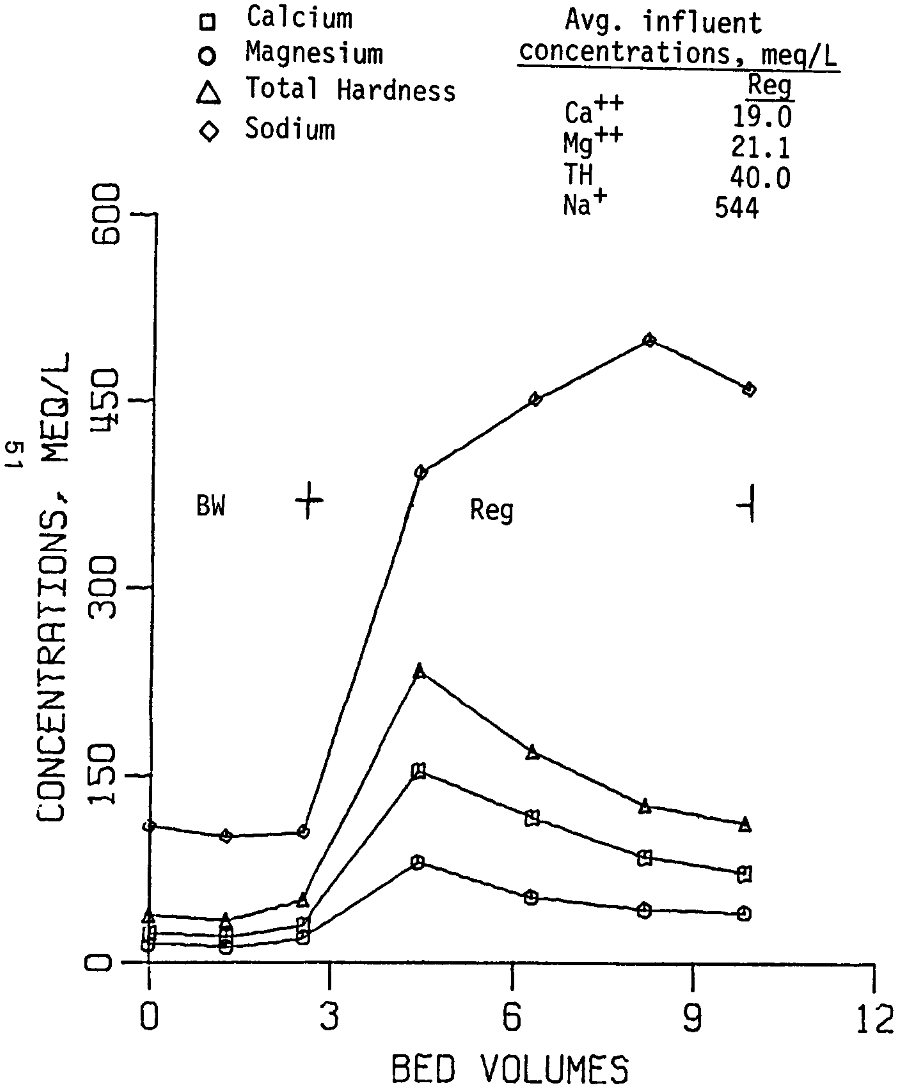
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.

SERVICE PERFORMANCE SUMMARY

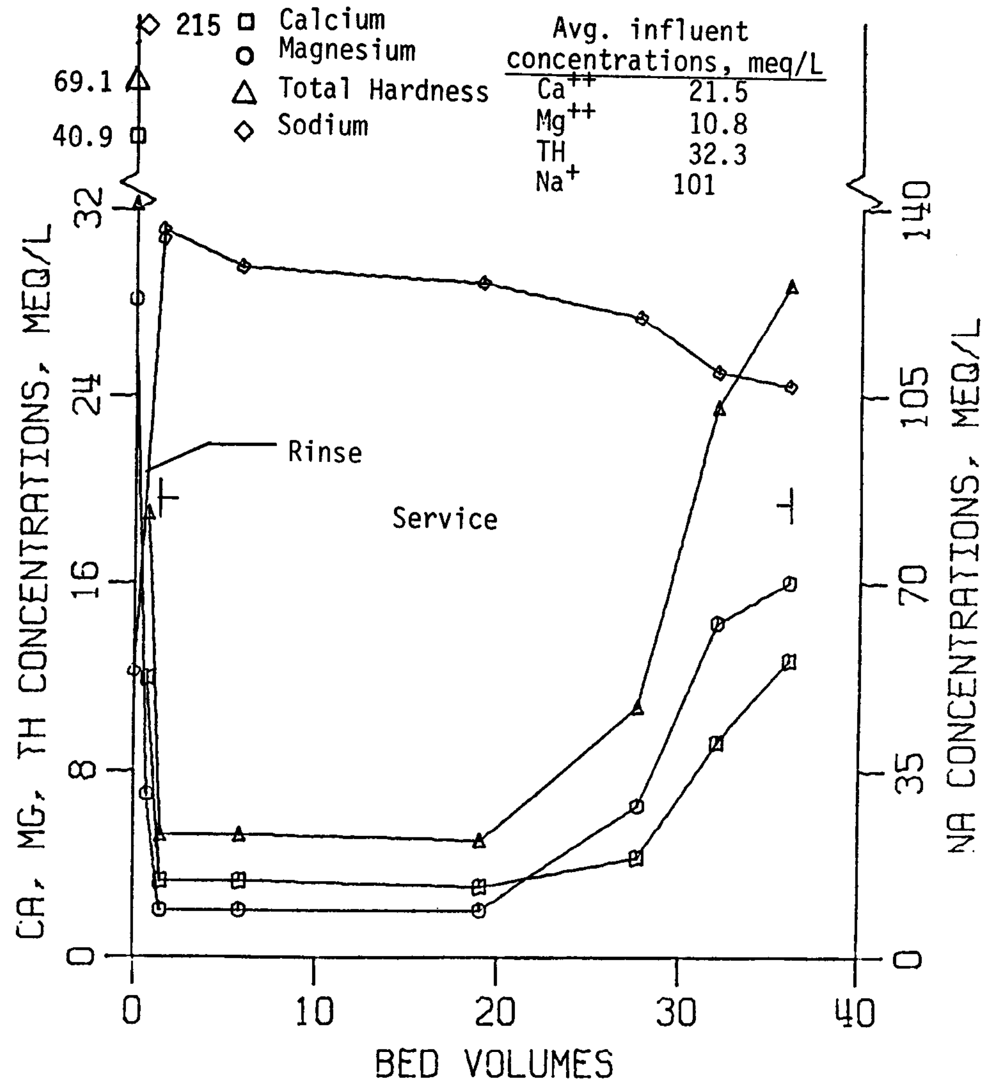
CYCLE L.01.97

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY	TIME-WEIGHTED RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L	MEQ/L·min
CA	21.54	4.63	16.91	79	.585	~~.327~~ 2.71
MG	10.78	5.16	5.62	52	.194	~~.109~~ 0.90
TH	32.32	9.79	22.53	70	.779	~~.436~~ 3.61
NA	101.20	123.20	-22.00			

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.01.97



MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.01.97



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.02.00

Date: 2/1/80

Cycle: L.02.12

Conditions: Feedwater - LaVerkin Springs - - lime-softened, pretreated
Regenerants - recycled regenerant and fresh ED brine

Control variables:	Target	Actual
Fresh regeneration conc. (mg/L TDS-calc.)	-	40 800
Fresh regeneration conc. (mg/L TDS-evap.)	-	39 800
Fresh regeneration flow rate (L/min)	12.0	12.1
Recycled regenerant flow rate (L/min)	24.0	24.0
Recycled regenerant volume (L)	1 600	1 591
Service termination point (meq/L Ca^{++})	12.0	12.2
Heat exchanger used	Yes	Yes
Packed bed regeneration mode used (i.e., resin hold-down)	No	No

Standard resin bed: Height[a] = 1 128 mm
Volume = 103.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.02.12

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.5	4 600	49.0	47.0	96.0
Spent regenerant (T-6)	7.4	4 600	52.0	49.0	101.0
Lime-softened feed (T-9)	7.2	1 350	20.6	11.4	32.0
Lime-softened feed (T-10)	7.1	1 320	21.2	10.4	31.6
Fresh ED brine (T-28)	6.0	5 150	16.2	21.8	38.0
IX product/ED feed (T-33)	5.7	1 400	3.0	5.6	8.6
Lime-softened feed (clearwell)	7.1	1 320	21.4	10.0	31.4

[a]The standard resin bed height was determined during run L.01.00.

OPERATING CONDITIONS

CYCLE L.02.12

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	261	2.53	26.1	.253	34.	28.8
REGEN 2	RE REGEN	SP REGEN	66	1591	15.4	24.0	.233	39.0	26.5
REGEN 3	FR REGEN	SP REGEN	73	880	8.54	12.1	.117	23.	11.8
DRAIN 1	(VENT)	WASTE	3	62	.60	20.7	.201	0.0	
RINSE	FEED	WASTE	10	150	1.46	15.0	.146	0.0	
SERVICE	FEED	PRODUCT	152	4550	44.2	29.9	.291	0.0	
DRAIN 2	(VENT)	WASTE	3	62	.60	20.7	.201	0.0	
			317						

Fresh Regenerant Volume Balance

Cycle L.02.12

Run L.02.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
05	1/30/80	750	-	4 210	-	80	0.89
06	1/30/80	746	-	4 020	-	80	0.93
07	1/31/80	747	-	4 190	-	80	0.89
08	1/31/80	880	-	4 390	-	80	1.00
09	1/31/80	883	-	4 350	-	80	1.01
10	1/31/80	878	-	4 290	-	80	1.02
11	2/1/80	885	-	4 430	-	80	1.00
12	2/1/80	880	-	4 550	-	80	0.97

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.02.12 (All samples composites except regenerations influent) (Analyzed at Boulder City on 3/12/80)

	Units	Regen 1, 2 influent	Regen 2 effluent[a]	Regen 3 Influent	Regen 3 Effluent	Rinse, service influent	Service effluent
pH	units	-	-	7.5	-	7.7	7.9
TDS (calculated)	mg/L	34 400	34 400	40 800	40 400	8 740	8 860
TDS (evaporated @ 180°C)	mg/L	34 300	34 300	39 800	39 700	8 660	8 690
Conductivity @ 25°C	mS/m	-	-	4 920	-	1 260	1 240
Silica	mg/L	0	0	15	40	15	19
Calcium	mg/L	1 040	1 340	380	1 320	440	75.0
Magnesium	mg/L	610	537	287	537	140	85.4
Sodium	mg/L	10 300	9 940	13 300	12 100	2 390	2 860
Potassium	mg/L	782	743	1 210	1 020	205	293
Iron, total	mg/L	0.4	0.4	0.28	0.6	0	0.06
Manganese, total	mg/L	<0.5	<0.5	0.12	<0.4	<0.05	<0.05
Strontium	mg/L	26	26	3.3	26	6.3	1.8
Bicarbonate	mg/L	92	104	76.3	0	48.2	47.6
Carbonate	mg/L	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-
Sulfate	mg/L	6 050	6 290	9 340	8 930	2 040	1 980
Chloride	mg/L	15 500	15 500	16 200	16 400	3 480	3 520
T-alkalinity as $CaCO_3$	mg/L	80	90	63	0	40	39
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0	0	0
T-phosphorus as PO_4	mg/L	0	0	1.0	0	1.4	1.3
E.F. [TDS(calculated)/cond.]		-	-	8.3	-	6.9	7.1
E.F. [TDS(evaporated)/cond.]		-	-	8.1	-	6.9	7.0
Σ Anions	meq/L	563.6	568.0	652.0	647.5	141.2	141.2
Σ Cations	meq/L	568.0	562.0	651.5	664.0	142.8	142.8
Control value	meq/L	-0.50	+0.67	+0.05	-1.63	-0.70	-0.70

[a]Due to an insufficient volume of individual samples to make a Regen 2 composite, only the sample collected at the halfway point of Regen 2 was used for the composite.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.02.12

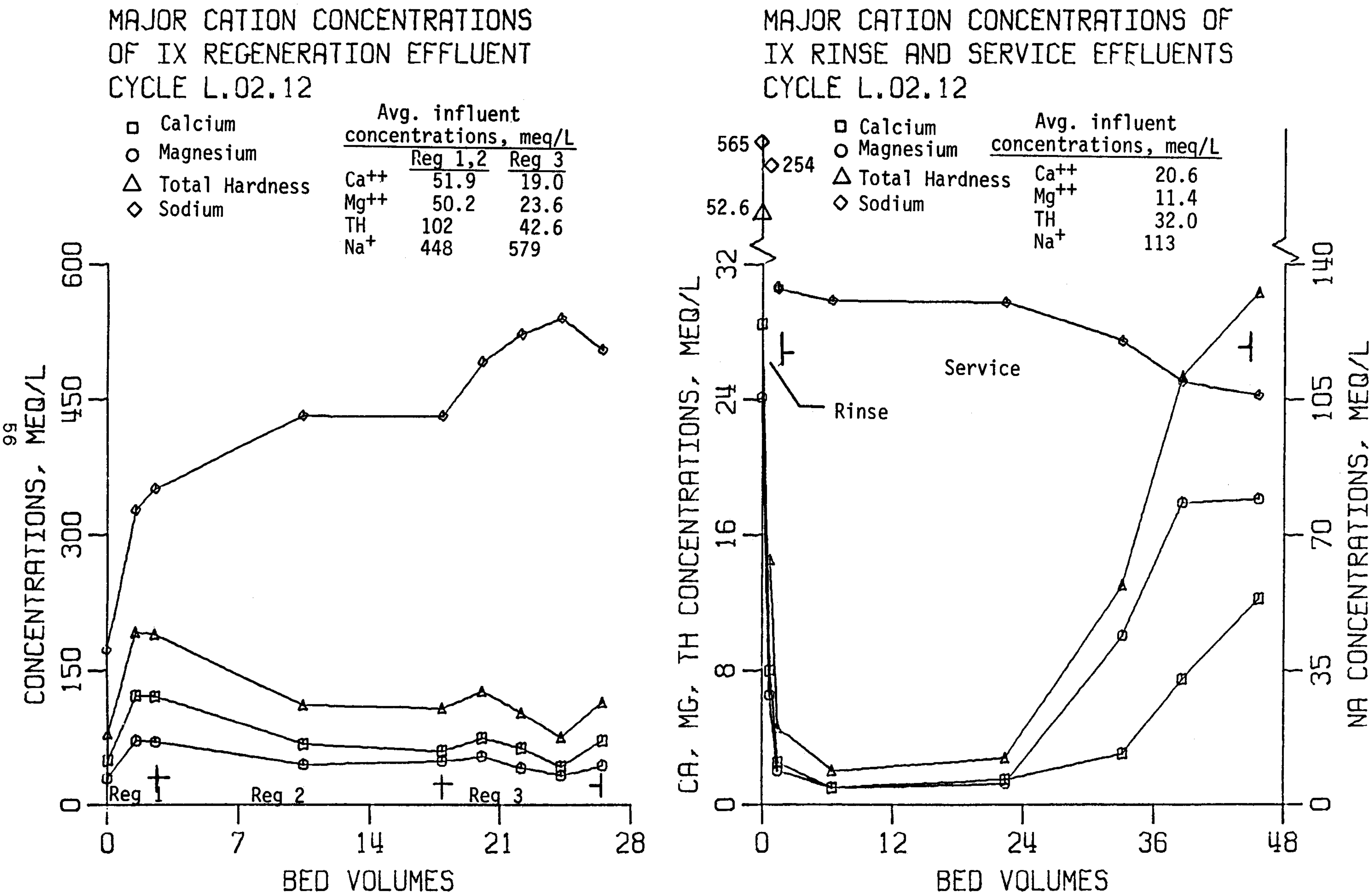
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	48.90	29.14	78.04	172.25
REGEN 1	EFFLUENT[a]	1.52	121.76	70.29	192.04	327.10
REGEN 2	EFFLUENT[a]	2.53	120.76	69.30	190.06	351.02
REGEN 2	INFLUENT	6.50	51.90	50.21	102.10	448.02
REGEN 2	EFFLUENT[a]	10.47	66.87	44.20	111.06	432.36
REGEN 3	EFFLUENT[a]	17.93	58.88	48.23	107.11	431.06
REGEN 3	INFLUENT	18.49	18.96	23.62	42.58	578.51
REGEN 3	EFFLUENT[a]	20.05	73.85	53.25	127.10	491.52
REGEN 3	EFFLUENT[a]	22.16	61.88	40.16	102.04	521.97
REGEN 3	EFFLUENT[a]	24.28	41.92	32.10	74.01	539.36
REGEN 3	EFFLUENT[a]	26.51	70.86	43.21	114.07	504.57
RINSE	EFFLUENT	0.00	23.44	24.12	52.56	565.40
RINSE	EFFLUENT	.73	7.98	6.53	14.51	254.02
RINSE	EFFLUENT	1.46	2.50	2.01	4.50	133.97
SERVICE	EFFLUENT	1.46	2.50	2.01	4.50	133.54
SERVICE	INFLUENT	3.49	20.71	12.02	32.73	103.96
SERVICE	EFFLUENT	6.40	1.00	1.00	2.00	130.49
SERVICE	INFLUENT	20.93	20.71	11.03	31.74	103.52
SERVICE	EFFLUENT	22.38	1.50	1.26	2.76	130.05
SERVICE	EFFLUENT	33.13	2.99	10.04	13.04	120.05
SERVICE	EFFLUENT	38.66	7.49	17.86	25.35	109.61
SERVICE	INFLUENT	45.63	20.46	11.03	31.49	104.39
SERVICE	EFFLUENT	45.63	12.23	18.11	30.33	106.13

[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.

SERVICE PERFORMANCE SUMMARY

CYCLE L.02.12

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L·MIN
CA	20.63	3.40	17.22	83	.761	~~.365~~ 2.40
MG	11.36	6.54	4.82	42	.213	~~.192~~ 0.67
TH	31.98	9.94	22.04	69	.974	~~.457~~ 3.07
NA	103.96	123.73	-19.77			



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.03.00

Date:	2/14/80		
Cycle:	L.03.35		
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - fresh ED Brine Source of backwash - IX feedwater		
		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS-calc.)	-	40 300
	Fresh regeneration conc. (mg/L TDS-evap.)	-	39 400
	Fresh regeneration flow rate (L/min)	12.0	11.9
	Recycled regenerant flow rate (L/min)	None	None
	Recycled regenerant volume (L)	None	None
	Service termination point (meq/L Ca^{++})	12.0	14.2
	Heat exchanger	Yes	Yes
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes
Standard resin bed:	Height[a] = 1 360 mm Volume = 115.0 L		

Chemical Compositions of Tank Waters (Prior to Cycle) L.03.35

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	7.2	4 500	12.4	89.0	101.4
Lime-softened feed (T-9)	7.2	1 300	19.8	9.8	29.6
Lime-softened feed (T-10)	7.2	1 300	20.0	9.8	29.8
Fresh ED brine (T-28)	6.6	5 150	15.8	19.0	34.8
IX product/ED feed (T-33)	6.4	1 400	3.8	4.2	8.0
Lime-softened feed (clearwell)	7.1	1 300	20.0	10.6	30.6

[a]The resin bed height at the end of regeneration with fresh regenerant was used as the standard resin height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.03.35

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	243	2.11	24.3	.211	30.	25.9
DRAIN 1	(VENT)	WASTE	3	62	.54	20.7	.180	0.0	
REGEN 3	FR REGEN	SP REGEN	75	896	7.79	11.9	.104	0.0	25.9
RINSE	FEED	WASTE	10	150	1.30	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	153	4590	39.9	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
			253						

Fresh Regenerant Volume Balance

Cycle L.03.35

Run L.03.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
06	2/7/80	754	-	4 360	-	80	0.86
23	2/11/80	748	41 200	4 270	8 780	80	0.88
25	2/12/80	803	-	4 600	-	80	0.87
26	2/12/80	762	-	4 090	-	80	0.93
27	2/12/80	747	-	4 400	-	80	0.85
28	2/13/80	751	-	4 270	-	80	0.88
29	2/13/80	743	-	4 480	-	80	0.83
30	2/13/80	890	-	4 290	-	80	1.04
31	2/13/80	895	-	4 560	-	80	0.98
32	2/13/80	902	-	4 520	-	80	1.00
33	2/13/80	896	-	4 730	-	80	0.95
34	2/14/80	897	-	4 720	-	80	0.95
35	2/14/80	896	-	4 590	-	80	0.98

Influent and Effluent Compositions during IX Regeneration and Service - Cycle L.03.35
(All samples composites except regeneration influent)
(Analyzed at Boulder City on 3/27/80)

	Units	Regeneration influent	Regeneration effluent	Rinse & service influent	Service effluent
pH	units	7.4	-	7.6	8.0
TDS (calculated)	mg/L	40 300	40 200	8 670	8 810
TDS (evaporated @ 180°C)	mg/L	39 400	39 200	8 610	8 630
Conductivity @ 25°C	mS/m	4 890	-	1 260	1 310
Silica	mg/L	14	0	16	16
Calcium	mg/L	360	2 280	410	100
Magnesium	mg/L	268	610	137	76.3
Sodium	mg/L	13 200	10 600	2 370	2 780
Potassium	mg/L	958	782	205	264
Iron, total	mg/L	0.37	0.40	0.08	0.07
Manganese, total	mg/L	0.15	<0.5	0.05	0.05
Strontium	mg/L	7.0	32	6.8	2.0
Bicarbonate	mg/L	88.5	189	39.7	52.5
Carbonate	mg/L	0	0	0	0
Hydroxide	mg/L	-	-	-	-
Sulfate	mg/L	9 100	9 700	1 960	2 000
Chloride	mg/L	16 300	16 100	3 540	3 540
T-alkalinity as $CaCO_3$	mg/L	73	160	33	43
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0
T-phosphorus as PO_4	mg/L	2.2	2.0	0.7	0.7
E.F. [TDS(calculated)/cond.]		8.2	-	6.9	6.7
E.F. [TDS(evaporated)/cond.]		8.1	-	6.8	6.6
Σ Anions	meq/L	649.0	657.8	141.0	142.3
Σ Cations	meq/L	638.5	644.0	140.0	139.0
Control value	meq/L	+1.03	+1.34	+0.44	+1.43

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.03.35

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	20.71	12.84	33.55	106.13
BACKWASH	EFFLUENT	1.27	19.71	12.84	32.55	103.09
REGEN 3	EFFLUENT[a]	2.11	20.76	12.84	33.60	105.70
REGEN 3	INFLUENT	3.15	17.96	22.06	40.02	574.16
REGEN 3	EFFLUENT[a]	4.06	158.68	72.26	230.95	380.17
REGEN 3	EFFLUENT[a]	6.05	106.79	42.14	148.93	478.47
REGEN 3	EFFLUENT[a]	8.01	78.84	30.12	108.97	517.62
REGEN 3	EFFLUENT[a]	9.87	57.88	28.15	86.03	539.36
RINSE	EFFLUENT	0.00	24.45	15.06	39.51	289.26
RINSE	EFFLUENT	.65	20.46	14.07	34.53	380.17
RINSE	EFFLUENT	1.30	2.74	2.01	4.75	140.50
SERVICE	EFFLUENT	1.30	2.74	2.01	4.75	137.45
SERVICE	INFLUENT	3.91	21.71	10.78	32.49	106.13
SERVICE	EFFLUENT	6.52	2.74	1.26	4.00	131.36
SERVICE	INFLUENT	20.35	22.21	10.78	32.99	103.09
SERVICE	EFFLUENT	21.65	2.99	1.26	4.25	130.06
SERVICE	EFFLUENT	31.83	5.99	10.53	16.52	118.75
SERVICE	EFFLUENT	37.04	10.73	17.86	28.59	107.00
SERVICE	INFLUENT	41.22	22.21	11.52	33.73	105.26
SERVICE	EFFLUENT	41.22	14.22	17.86	32.08	105.26

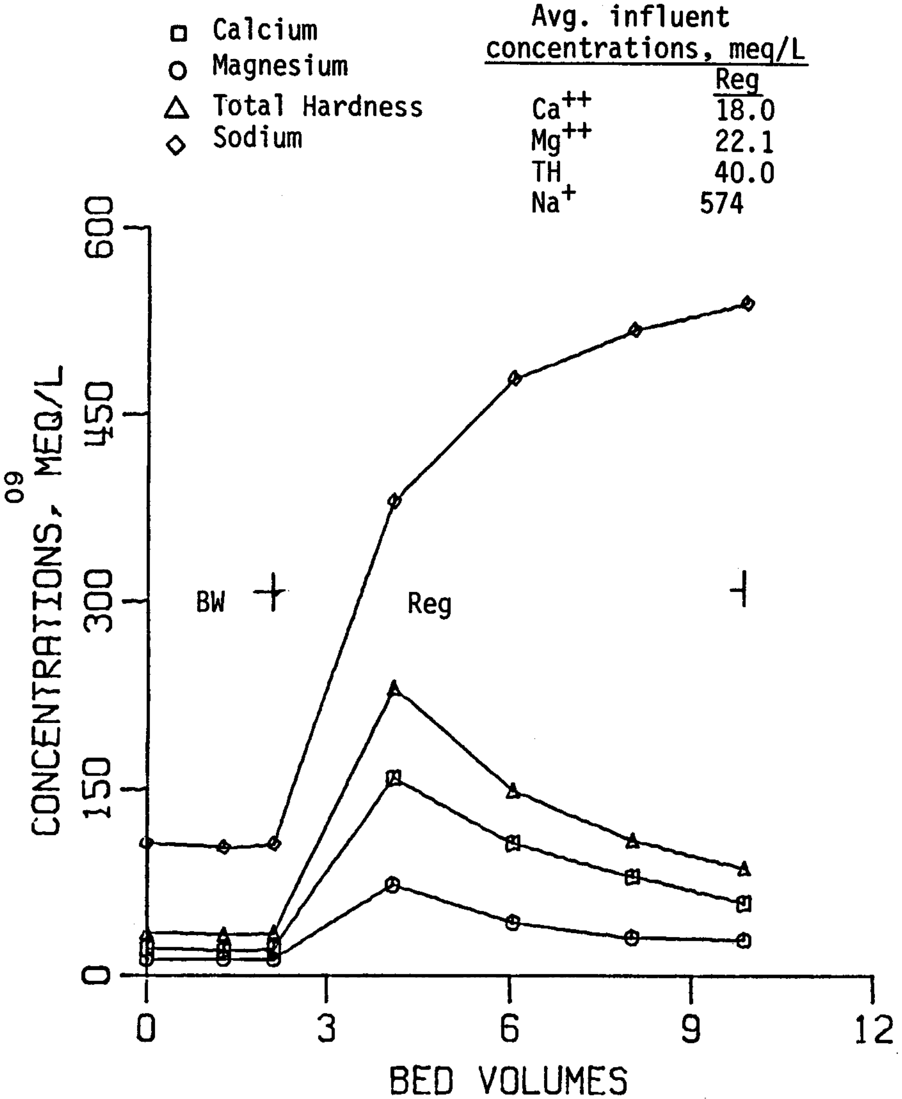
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.

SERVICE PERFORMANCE SUMMARY

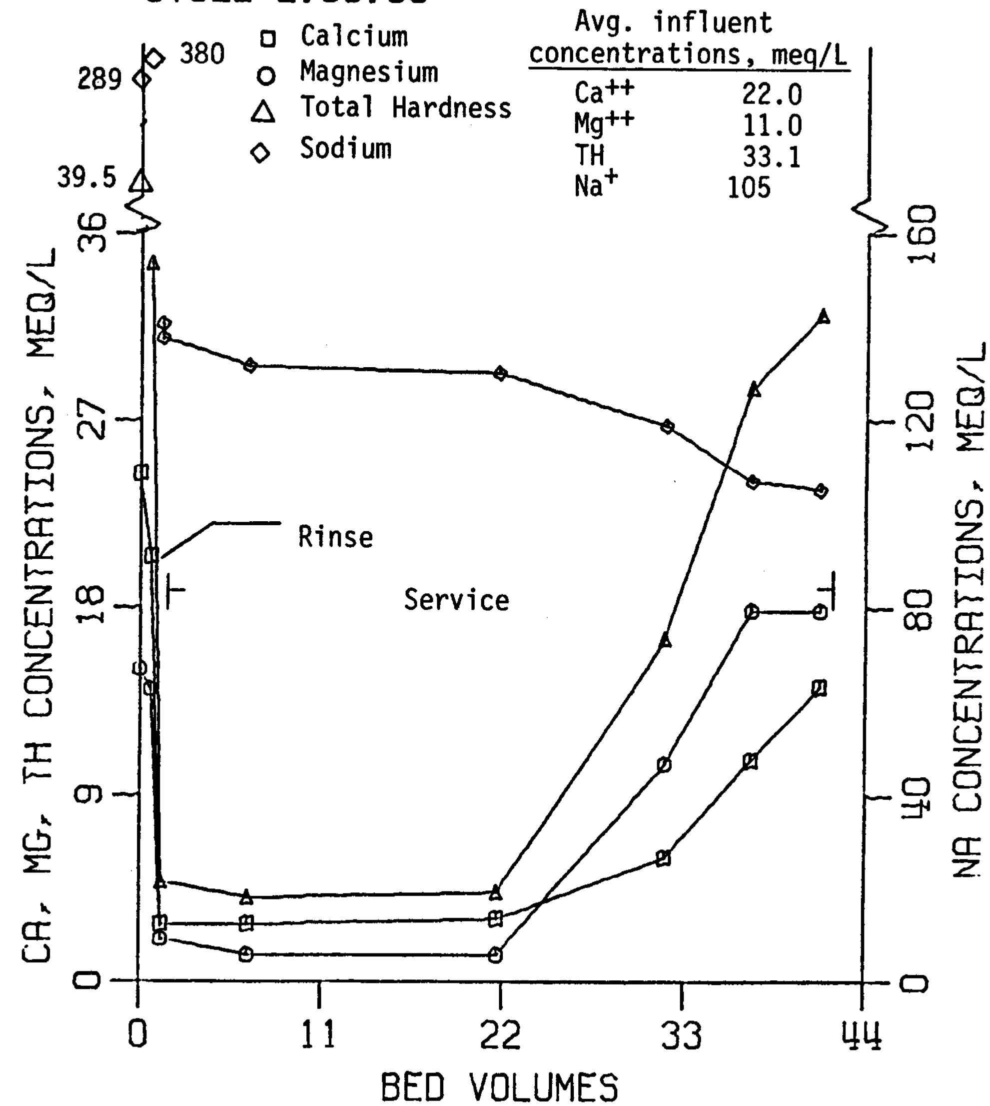
CYCLE L.03.35

	AVERAGE CONCENTRATIONS, MEQ/L			REMOVAL	RESIN CAPACITY	TIME-WEIGHTED RESIN CAPACITY
	INFLUENT	EFFLUENT	DIFFERENCE	%	EQ/L	mEQ/L·min
CA	22.04	4.99	17.05	77	.681	~~.408~~ 2.69
MG	11.03	5.92	5.11	46	.204	~~.122~~ 0.81
TH	33.07	10.91	22.16	67	.885	~~.531~~ 3.50
NA	104.83	124.68	-19.86			

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.03.35



MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.03.35



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.04.00

Date:	2/17/80		
Cycle:	L.04.11		
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine		
		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS-calc.)	-	40 100
	Fresh regeneration conc. (mg/L TDS-evap.)	-	39 800
	Fresh regeneration flow rate (L/min)	12.0	12.0
	Recycled regenerant flow rate (L/min)	24.0	24.1
	Recycled regenerant volume (L)	1 600	1 573
	Service termination point (meq/L Ca^{++})	12.0	13.8
	Heat exchanger used	Yes	Yes
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes
Standard resin bed:	Height[a] = 1 310 mm Volume = 115.0 L		

Chemical Compositions of Tank Waters (Prior to Cycle) L.04.11

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.7	4 600	47.2	37.6	84.8
Spent regenerant (T-6)	7.6	4 700	11.0	75.8	86.8
Lime-softened feed (T-9)	7.2	1 300	21.0	8.8	29.8
Lime-softened feed (T-10)	7.3	1 300	20.6	9.6	30.2
Fresh ED brine (T-28)	6.5	5 150	16.0	24.2	40.2
IX product/ED feed (T-33)	6.4	1 350	3.2	8.6	11.8
Lime-softened feed (clearwell)	7.2	1 300	21.0	8.8	29.8

[a]The resin bed height at the end of drain-down after the service mode was used as the standard resin height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.04.11

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	249	2.17	24.9	.217	39.	26.0
DRAIN 1	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
REGEN 2	RE REGEN	SP REGEN	65	1573	13.68	24.2	.210	1.	25.8
REGEN 3	FR REGEN	SP REGEN	92	1100	9.57	12.0	.104	.8	25.5
RINSE	FEED	WASTE	10	150	1.30	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	189	5670	49.3	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
			370						

Fresh Regenerant Volume Balance

Cycle L.04.11

Run L.04.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
06	2/15/80	1 170	-	5 540	-	80	1.06
07	2/16/80	1 170	-	5 430	-	80	1.08
08	2/16/80	1 176	-	5 480	-	80	1.07
09	2/16/80	1 107	-	5 440	-	80	1.02
10	2/17/80	1 100	-	5 810	-	80	0.95
11	2/17/80	1 100	-	5 670	-	80	0.97

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.04.11
(All samples composites except regenerations influent)
(Analyzed at Boulder City on 3/28/80)

	Units	Regen 1,2 influent	Regen 1 effluent	Regen 3 influent	Regen 3 effluent	Rinse & service influent	Rinse effluent	Service effluent
pH	units	-	-	7.1	-	7.7	7.6	7.9
TDS (calculated)	mg/L	36 300	27 900	40 100	40 100	8 410	15 400	8 640
TDS (evaporated @ 180°C)	mg/L	35 100	27 600	39 800	38 900	8 470	15 400	8 500
Conductivity @ 25°C	mS/m	-	-	4 920	-	1 230	2 190	1 290
Silica	mg/L	50	40	18	40	14	15	15
Calcium	mg/L	1 160	2 140	350	1 200	405	205	60
Magnesium	mg/L	537	744	317	512	125	79.3	91.5
Sodium	mg/L	10 900	6 510	13 200	11 900	2 270	4 950	2 740
Potassium	mg/L	860	469	1 060	938	205	401	254
Iron, total	mg/L	0.40	0.40	0.32	0.40	0.06	0.10	0.05
Manganese, total	mg/L	<0.40	<0.50	0.09	<0.50	<0.05	<0.05	<0.05
Strontium	mg/L	26	29	5	22	5.8	3.3	1.3
Bicarbonate	mg/L	122	98	97	134	42.7	57.3	47.6
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	7 100	5 620	9 190	9 700	1 990	3 640	1 990
Chloride	mg/L	15 600	12 300	15 900	15 700	3 370	6 070	3 460
T-alkalinity as $CaCO_3$	mg/L	100	80	80	110	35	47	39
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0	0	0	0
T-phosphorus as PO_4	mg/L	0	0.1	2.7	0.1	1.0	1.9	1.5
E.F. [TDS(calculated)/cond.]		-	-	8.2	-	6.8	7.0	6.7
E.F. [TDS(evaporated)/cond.]		-	-	8.1	-	6.9	7.0	6.6
Σ Anions	meq/L	588.7	465.6	641.0	647.3	137.0	247.6	139.7
Σ Cations	meq/L	598.0	463.0	645.5	644.0	134.3	242.0	136.0
Control value	meq/L	-1.01	+0.36	-0.45	+0.33	+1.21	+1.42	+1.63

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.04.11

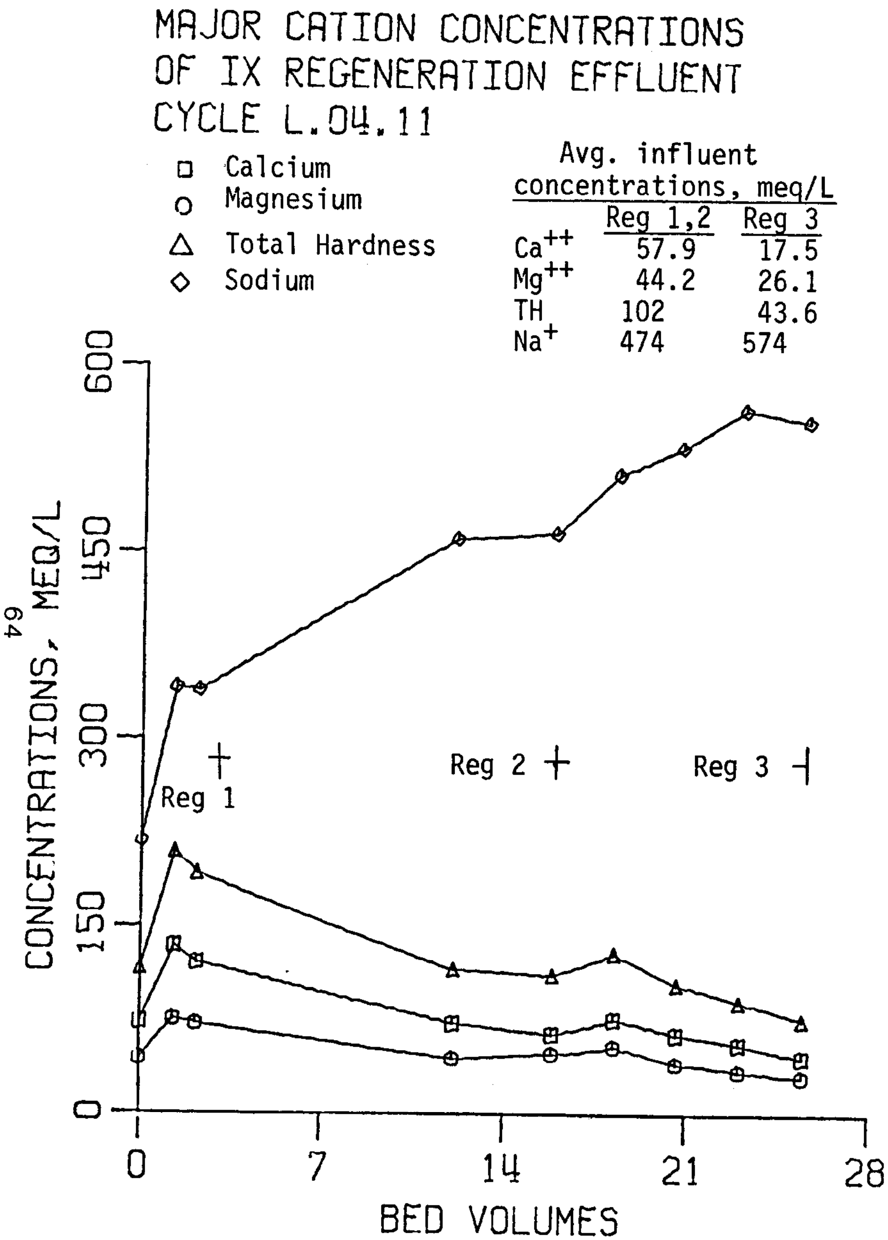
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	72.85	43.21	116.06	217.92
REGEN 1	EFFLUENT[a]	1.30	134.73	75.31	210.04	341.02
REGEN 2	EFFLUENT[a]	2.17	121.76	71.28	193.03	339.28
REGEN 2	INFLUENT	8.69	57.88	44.20	102.08	474.12
REGEN 2	EFFLUENT[a]	12.06	71.86	44.20	116.05	461.07
REGEN 3	EFFLUENT[a]	15.84	63.87	48.23	112.10	465.42
REGEN 3	INFLUENT	17.10	17.47	26.09	43.56	574.16
REGEN 3	EFFLUENT[a]	18.24	75.85	54.24	130.09	513.27
REGEN 3	EFFLUENT[a]	20.64	63.87	40.16	104.04	535.02
REGEN 3	EFFLUENT[a]	23.04	55.89	34.16	90.04	565.46
REGEN 3	EFFLUENT[a]	25.44	45.91	30.12	76.03	556.76
RINSE	EFFLUENT	0.00	19.46	12.26	31.72	190.95
RINSE	EFFLUENT	.65	9.23	10.29	19.52	351.46
RINSE	EFFLUENT	1.30	2.50	2.26	4.76	137.45
SERVICE	EFFLUENT	1.30	2.50	2.26	4.76	138.76
SERVICE	INFLUENT	4.43	22.21	11.28	33.48	104.39
SERVICE	EFFLUENT	7.30	2.50	2.01	4.50	131.36
SERVICE	INFLUENT	23.48	21.71	11.28	32.98	103.52
SERVICE	EFFLUENT	24.78	2.99	2.01	5.00	130.93
SERVICE	EFFLUENT	36.52	3.74	12.02	15.76	120.05
SERVICE	EFFLUENT	42.52	7.49	21.32[b]	28.80[b]	107.87
SERVICE	EFFLUENT	48.52	12.23	19.59	31.81	104.83
SERVICE	INFLUENT	50.61	21.96	11.77	33.73	102.22
SERVICE	EFFLUENT	50.61	13.72	18.11	31.83	105.70

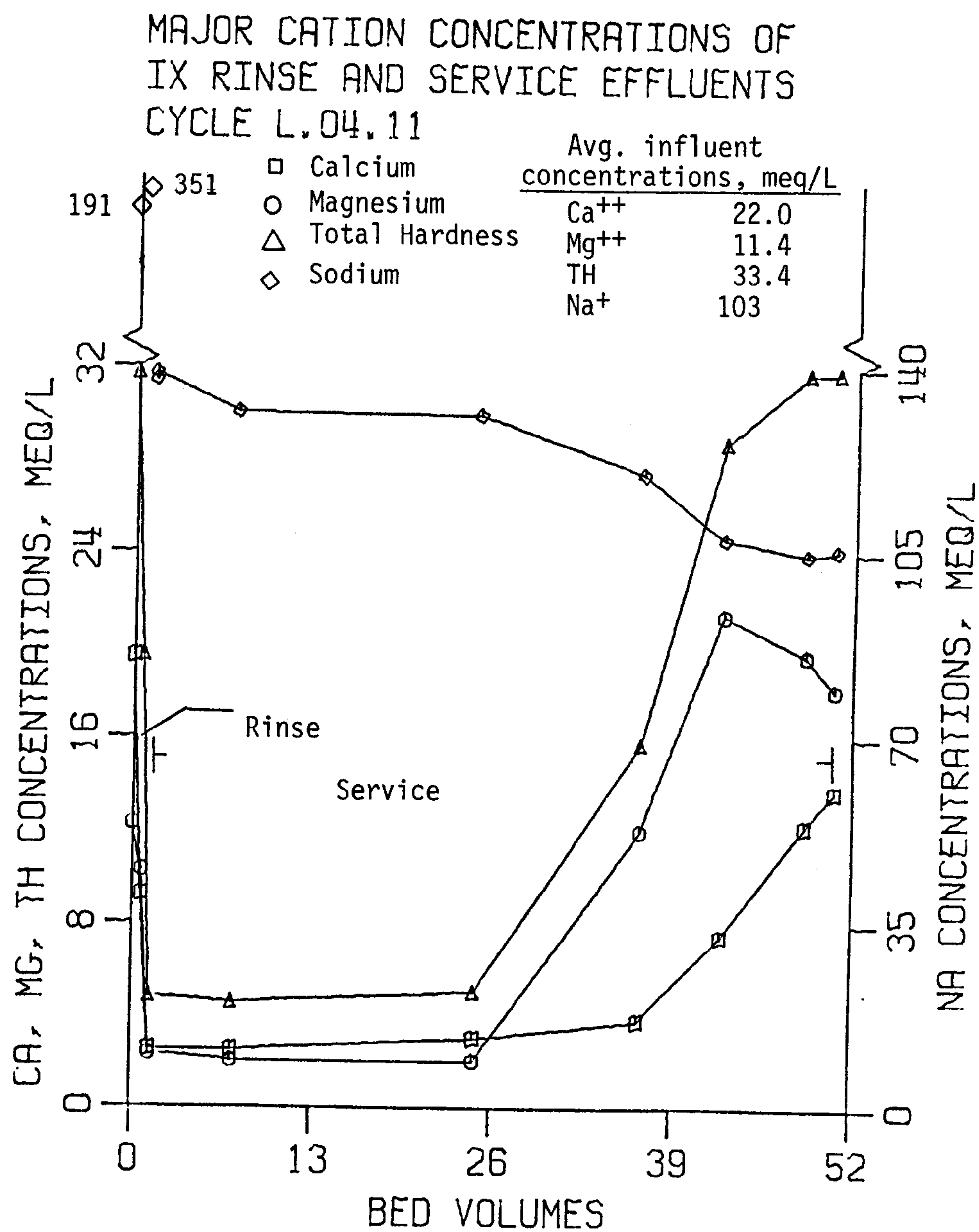
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b]Questionable chemical analysis result.

SERVICE PERFORMANCE SUMMARY

CYCLE L.04.11

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY mEQ/L · min
CA	21.96	4.51	17.45	79	.860	~~.429~~ 2.32
MG	11.44	7.96	3.48	30	.172	~~.088~~ 0.47
TH	33.40	12.47	20.93	63	1.032	~~.526~~ 2.79
NA	103.38	124.07	-20.69			





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.05.00

Date:	2/28/80
Cycle:	L.05.54
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - fresh ED brine Source of backwash - IX feedwater

Control variables:	Target	Actual
Fresh regeneration conc. (mg/L TDS-calc.)	-	~~94 900~~
Fresh regeneration conc. (mg/L TDS-evap.)	-	92 000
Fresh regeneration flow rate (L/min)	24.0	26.0
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	6.0	7.8
Heat exchanger used	Yes	Yes
Packed bed regeneration mode used (i.e., resin hold-down)	No	No

Standard resin bed: Height[a] = 1 445 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.05.54

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	7.2	7 150	63.0	94.0	157.0
Lime-softened feed (T-9)	7.2	1 400	23.2	8.0	31.2
Lime-softened feed (T-10)	7.3	1 400	21.0	9.8	30.8
Fresh ED brine (T-28)	6.5	9 700	24.8	28.8	53.6
IX product/ED feed (T-33)	6.5	1 410	3.6	3.6	7.2
Lime-softened feed (clearwell)	7.8	1 400	21.4	9.8	31.2

[a]The resin bed height at the end of drain-down after regeneration with fresh ED brine was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.05.54

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	240	2.09	24.0	.209	20.	26.6
DRAIN 1	(VENT)	WASTE	3	62	.54	20.7	.180	0.0	
REGEN 3	FR REGEN	SP REGEN	8	200	1.74	26.0	.226	30.	26.8
DRAIN 2	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
RINSE	FEED	WASTE	20	300	2.61	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	73	2190	19.0	30.0	.261	0.0	
DRAIN 3	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
			118						

Fresh Regenerant Volume Balance

Cycle L.05.54

Run L.05.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
33	2/25/80	600	100 820	3 840	9 290	90	1.56
34	2/25/80	597	100 820	3 420	9 290	90	1.75
35	2/26/80	600	-	3 970	-	90	1.51
36	2/26/80	600	-	3 430	-	90	1.75
37	2/26/80	350	-	2 940	-	90	1.19
38	2/26/80	359	-	3 780	-	90	0.95
39	2/26/80	359	-	2 910	-	90	1.23
40	2/26/80	353	-	2 740	-	90	1.29
41	2/26/80	350	-	2 790	-	90	1.25
42	2/26/80	350	-	2 570	-	90	1.36
43	2/27/80	350	-	2 570	-	90	1.36
44	2/27/80	350	-	2 560	-	90	1.37
45	2/27/80	240	-	2 430	-	90	0.99
46	2/27/80	241	-	2 250	-	90	1.07
47	2/27/80	239	-	2 200	-	90	1.09
48	2/27/80	236	-	2 160	-	90	1.09
49	2/27/80	234	-	2 300	-	90	1.02
50	2/28/80	202	-	2 100	-	90	0.96
51	2/28/80	205	-	2 140	-	90	0.96
52	2/28/80	199	-	1 920	-	90	1.04
53	2/28/80	199	-	1 920	-	90	1.04
54	2/28/80	200	-	2 190	-	90	0.91

Influent and Effluent Compositions during IX Regeneration and Service - Cycle L.05.54
(All samples composites except regeneration influent)
(Analyzed at Boulder City on 3/28/80)

	Units	Regeneration Influent	Regeneration Effluent	Rinse & service influent	Service effluent
pH	units	7.3	-	7.8	7.5
TDS (calculated)	mg/L	94 900	54 100	8 560	8 680
TDS (evaporated @ 180°C)	mg/L	92 000	53 200	8 550	8 660
Conductivity @ 25°C	mS/m	9 340	-	1 260	1 320
Silica	mg/L	25	0	13	14
Calcium	mg/L	490	3 900	420	80.0
Magnesium	mg/L	366	1 190	131	39.7
Sodium	mg/L	30 600	12 900	2 390	2 920
Potassium	mg/L	1 880	1 080	215	244
Iron, total	mg/L	0.68	0.60	0.05	0.07
Manganese, total	mg/L	0.21	<0.05	<0.05	<0.05
Strontium	mg/L	6.3	50	6.5	1.0
Bicarbonate	mg/L	82.4	91	43.3	43.3
Carbonate	mg/L	0	0	0	0
Hydroxide	mg/L	-	-	-	-
Sulfate	mg/L	25 600	13 200	1 940	1 940
Chloride	mg/L	35 900	21 300	3 440	3 430
T-alkalinity as $CaCO_3$	mg/L	68	80	36	36
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0
T-phosphorus as PO_4	mg/L	1.2	1.0	0.8	0.9
E.F. [TDS(calculated)/cond.]		10.2	-	6.8	6.6
E.F. [TDS(evaporated)/cond.]		9.9	-	6.8	6.6
Σ Anions	meq/L	1 481.0	857.2	138.2	137.8
Σ Cations	meq/L	1 435.0	882.5	141.3	140.5
Control value	meq/L	+1.99	-1.89	+1.36	-1.20

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.05.54

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	27.45	16.79	44.24	133.97
BACKWASH	EFFLUENT	1.25	18.71	12.02	30.73	116.57
REGEN 3	EFFLUENT[a]	2.09	142.22	77.86	220.08	405.39
REGEN 3	INFLUENT	2.31	24.45	30.12	54.57	1331.01
REGEN 3	EFFLUENT[a]	2.53	197.11	100.41	297.52	535.02
REGEN 3	EFFLUENT[a]	2.75	261.98	125.93	387.90	639.41
REGEN 3	EFFLUENT[a]	2.98	314.37	128.40	442.77	813.40
REGEN 3	EFFLUENT[a]	3.67	162.18	77.85	240.04	739.45
RINSE	EFFLUENT	0.00	39.92	83.13	123.05	1135.28
RINSE	EFFLUENT	1.30	20.96	12.59	33.55	271.42
RINSE	EFFLUENT	2.61	4.74	3.01	7.75	134.84
SERVICE	EFFLUENT	2.61	4.74	3.01	7.75	134.41
SERVICE	INFLUENT	8.09	22.21	10.78	32.99	102.22
SERVICE	EFFLUENT	9.13	2.25	2.51	4.76	127.88
SERVICE	INFLUENT	10.17	22.21[b]	11.28	33.48	101.35
SERVICE	EFFLUENT	11.22	4.74[b]	2.77	7.51	126.14
SERVICE	EFFLUENT	15.65	2.50	3.01	5.51	123.97
SERVICE	EFFLUENT	17.74	2.50	3.77	6.26	122.23
SERVICE	EFFLUENT	19.83	5.74	3.77	9.51	118.75
SERVICE	INFLUENT	21.65	21.96	10.78	32.74	100.48
SERVICE	EFFLUENT	21.65	7.73	8.56	16.29	117.01

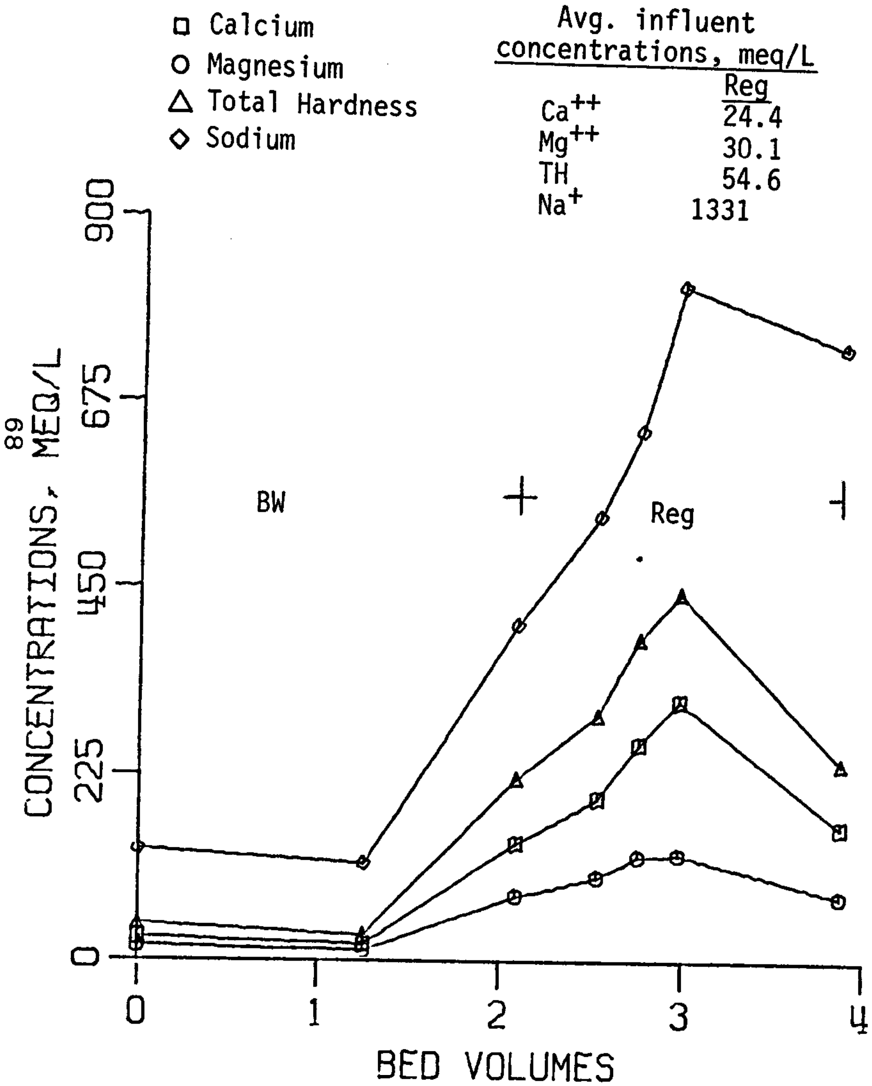
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] Inconsistent, apparently erroneous chemical analyses, deleted from calculation.

SERVICE PERFORMANCE SUMMARY

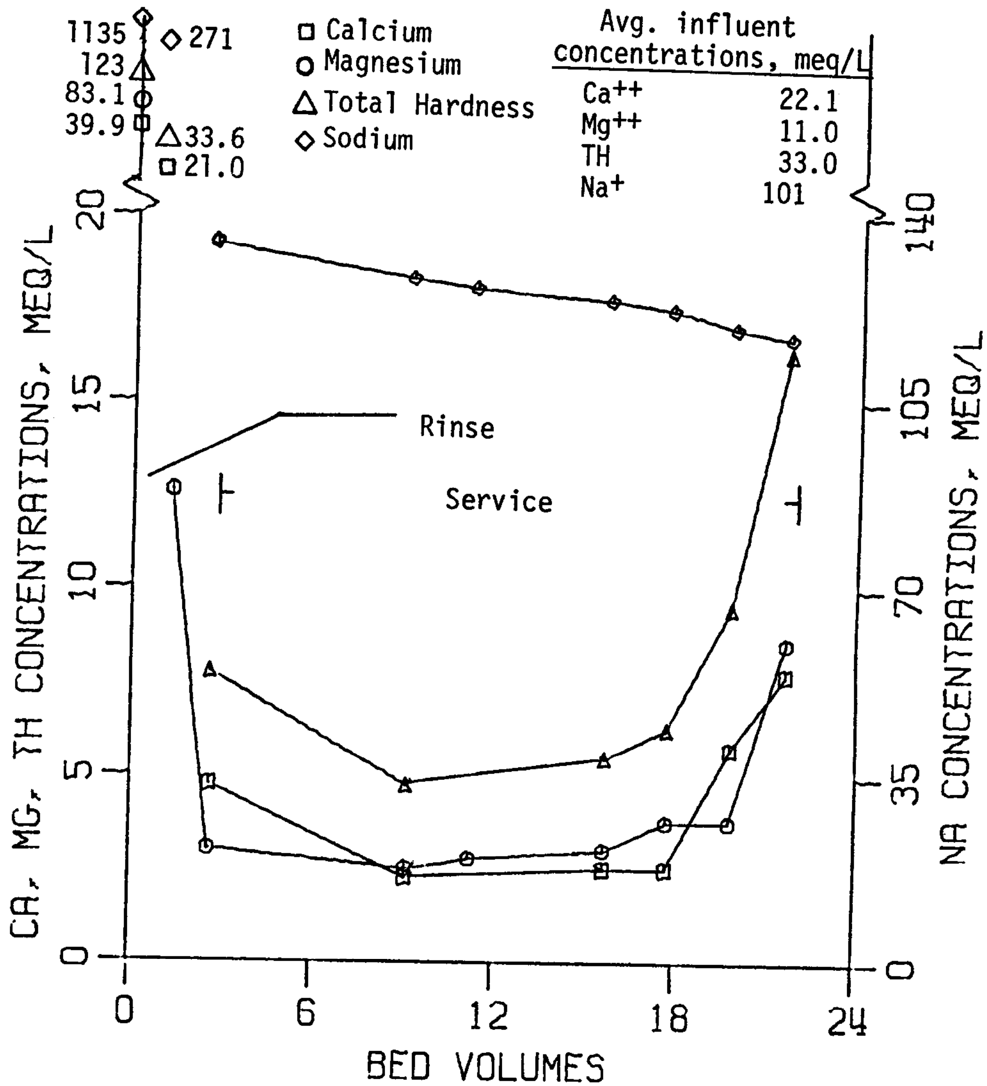
CYCLE L.05.54

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L·HR
CA	22.12	3.38	18.74	85	.341	~~.211~~ 2.89
MG	10.95	3.28	7.66	70	.146	~~.098~~ 1.24
TH	33.07	6.67	25.58	77	.487	~~.302~~ 4.13
NA	101.35	125.95	-24.60			

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.05.54



MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.05.54



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.10.00

Date:	3/8/80
Cycle:	L.10.14
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS-calc.)	-	94 000
Fresh regeneration conc. (mg/L TDS-evap.)	-	93 400
Fresh regeneration flow rate (L/min)	24.0	23.7
Recycled regenerant flow rate (L/min)	24.0	23.2
Recycled regenerant volume (L)	1 600	1 594
Service termination point (meq/L Ca^{++})	6.0	8.2
Heat exchanger used	Yes	Yes
Packed bed regeneration mode used (i.e., resin hold-down)	No	No

Standard resin bed: Height[a] = 1 320 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.10.14

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.6	8 100	45.0	93.0	138.0
Spent regenerant (T-6)	7.5	8 210	44.0	91.0	135.0
Lime-softened feed (T-9)	7.3	1 250	21.6	8.2	29.8
Lime-softened feed (T-10)	7.4	1 290	23.8	9.2	33.0
Fresh ED brine (T-28)	6.5	9 910	23.2	29.6	52.8
IX product/ED feed (T-33)	6.0	1 250	1.3	2.5	3.8
Lime-softened feed (clearwell)	7.4	1 220	21.0	9.4	30.4

[a]The resin bed height at the end of drain-down after regeneration with fresh regenerant was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.10.14

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	250	2.17	25.0	.217	42.	19.5
REGEN 2	RE REGEN	SP REGEN	69	1594	13.9	23.1	.201	42.0	26.6
REGEN 3	FR REGEN	SP REGEN	22	522	4.54	23.6	.205	42.	26.4
DRAIN 1	(VENT)	WASTE	3	62	.54	20.7	.180	0.0	
RINSE	FEED	WASTE	15	220	1.91	14.7	.128	0.0	
SERVICE	FEED	PRODUCT	187	5610	48.8	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
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Fresh Regenerant Volume Balance

Cycle L.10.14

Run L.10.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
02	3/4/80	501	-	5 130	-	90	0.98
03	3/4/80	499	-	4 950	-	90	1.01
04	3/4/80	504	-	5 190	-	90	0.97
05	3/5/80	499	-	5 480	-	90	0.91
06	3/5/80	499	-	5 490	-	90	0.91
08	3/6/80	602	-	5 550	-	90	1.08
09	3/6/80	601	-	5 300	-	90	1.13
10	3/6/80	601	-	5 560	-	90	1.08
11	3/7/80	599	-	5 370	-	90	1.12
12	3/7/80	522	-	5 670	-	90	0.92
13	3/8/80	522	-	5 500	-	90	0.95
14	3/8/80	522	-	5 610	-	90	0.93

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.10.14
(All samples composites except regenerations influent)
(Analyzed at Boulder City on 3/31/80)

	Units	Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & service influent	Service effluent
pH	units	-	-	-	7.2	-	7.6	7.5
TDS (calculated)	mg/L	71 200	52 300	69 400	94 000	88 400	8 670	8 930
TDS (evaporated @ 180°C)	mg/L	69 000	52 500	68 500	93 400	86 800	8 550	8 710
Conductivity @ 25°C	mS/m	-	-	-	9 460	-	1 240	1 320
Silica	mg/L	40	40	40	20	40	13	13
Calcium	mg/L	1 100	3 680	2 150	330	1 200	435	35.0
Magnesium	mg/L	1 280	1 490	1 340	549	1 070	128	58.0
Sodium	mg/L	22 800	12 500	20 500	32 100	28 400	2 370	2 970
Potassium	mg/L	1 470	938	1 370	2 250	2 050	215	293
Iron, total	mg/L	0.7	0.5	0.6	0.68	0.4	0.06	0.05
Manganese, total	mg/L	<0.5	<0.05	<0.05	0.28	<0.04	<0.04	<0.04
Strontium	mg/L	30	50	43	3.4	40	3.0	0.4
Bicarbonate	mg/L	134.0	110.0	122.0	131.0	140.0	47.0	46.4
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	0	0	0	0	0	0	0
Sulfate	mg/L	12 100	9 310	11 900	22 600	20 300	1 970	2 000
Chloride	mg/L	32 300	24 200	32 000	36 100	35 200	3 510	3 540
T-alkalinity as $CaCO_3$	mg/L	110	90	100	107	120	39	38
P-alkalinity as $CaCO_3$	mg/L	0	0	0	0	0	0	0
T-phosphorus as PO_4	mg/L	0	0.	0	0.1	0	0.5	0.6
E.F. [TDS(calculated)/cond.]		-	-	-	9.9	-	7.0	6.8
E.F. [TDS(evaporated)/cond.]		-	-	-	9.9	-	6.9	6.6
Σ Anions	meq/L	1 116.0	877.5	1 150.0	1 490.0	1 417.0	140.5	142.2
Σ Cations	meq/L	1 190.0	874.0	1 145.0	1 514.0	1 435.0	140.8	143.0
Control value	meq/L	-1.32	+0.26	-0.26	-1.03	-0.82	-0.13	-0.35

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.10.14

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	144.71	100.41	245.12	377.56
REGEN 1	EFFLUENT[a]	1.30	224.55	145.68	370.23	674.21
REGEN 2	EFFLUENT[a]	2.17	205.09	143.21	348.30	743.80
REGEN 2	INFLUENT	5.60	54.89	105.35	160.24	991.74
REGEN 2	EFFLUENT[a]	9.02	79.84	102.88	182.72	935.19
REGEN 3	EFFLUENT[a]	16.06	64.87	102.88	167.75	952.59
REGEN 3	INFLUENT	16.68	16.47	45.19	61.65	1396.26
REGEN 3	EFFLUENT[a]	17.30	64.87	105.35	170.22	1217.92
REGEN 3	EFFLUENT[a]	18.33	59.88	77.86	137.74	1265.77
REGEN 3	EFFLUENT[a]	19.57	57.39	72.84	130.22	1300.57
REGEN 3	EFFLUENT[a]	20.60	47.41	62.80	110.20	1365.81
RINSE	EFFLUENT	0.00	24.95	49.22	74.17	1352.76
RINSE	EFFLUENT	1.02	7.73	12.02	19.75	508.92
RINSE	EFFLUENT	1.91	1.25	1.26	2.51	145.28
SERVICE	EFFLUENT	1.91	1.25	1.51	2.75	142.67
SERVICE	INFLUENT	5.04	21.96	10.53	32.49	101.35
SERVICE	EFFLUENT	8.17	.21	1.26	1.47	132.23
SERVICE	INFLUENT	24.87	21.96	10.53	32.49	101.76
SERVICE	EFFLUENT	26.43	.19	1.00	1.19	127.01
SERVICE	EFFLUENT	38.70	1.25	4.02	5.26	124.84
SERVICE	EFFLUENT	44.70	2.50	16.54	19.04	115.70
SERVICE	INFLUENT	50.70	22.46	11.03	33.48	100.91
SERVICE	EFFLUENT	50.70	8.23	21.07	29.30	105.26

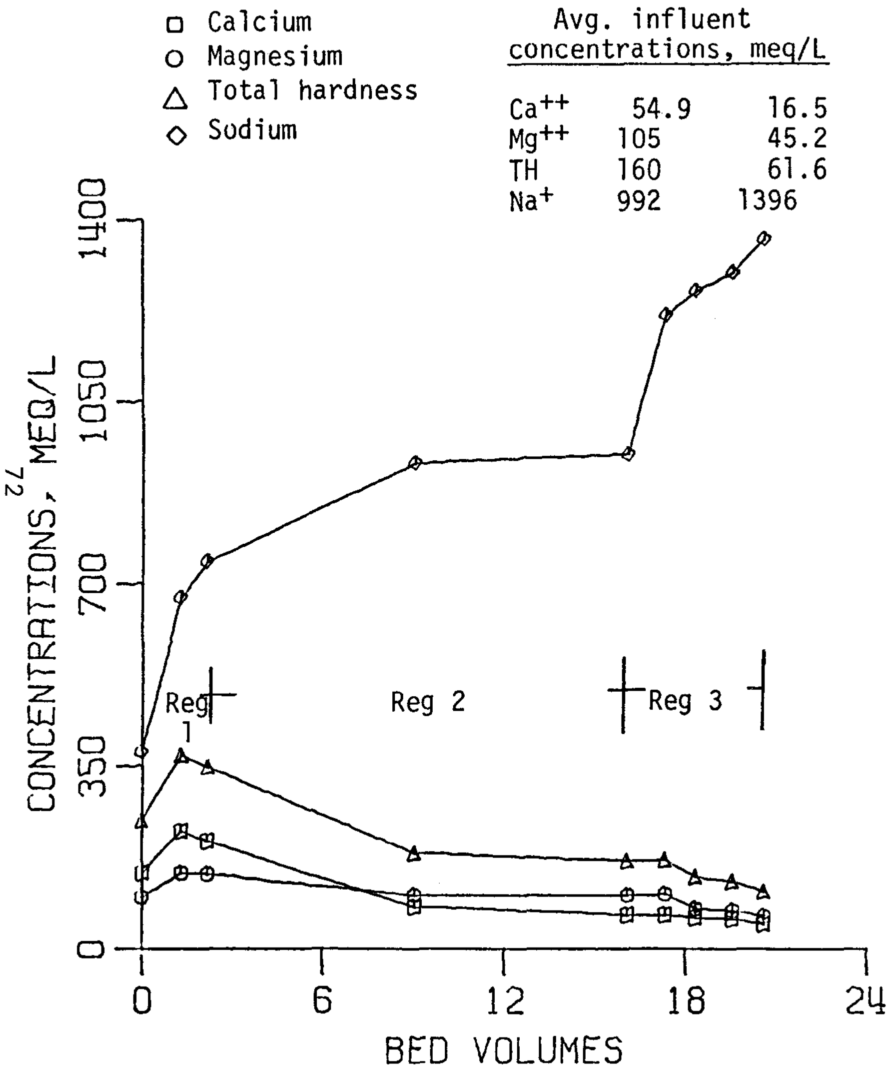
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.

SERVICE PERFORMANCE SUMMARY

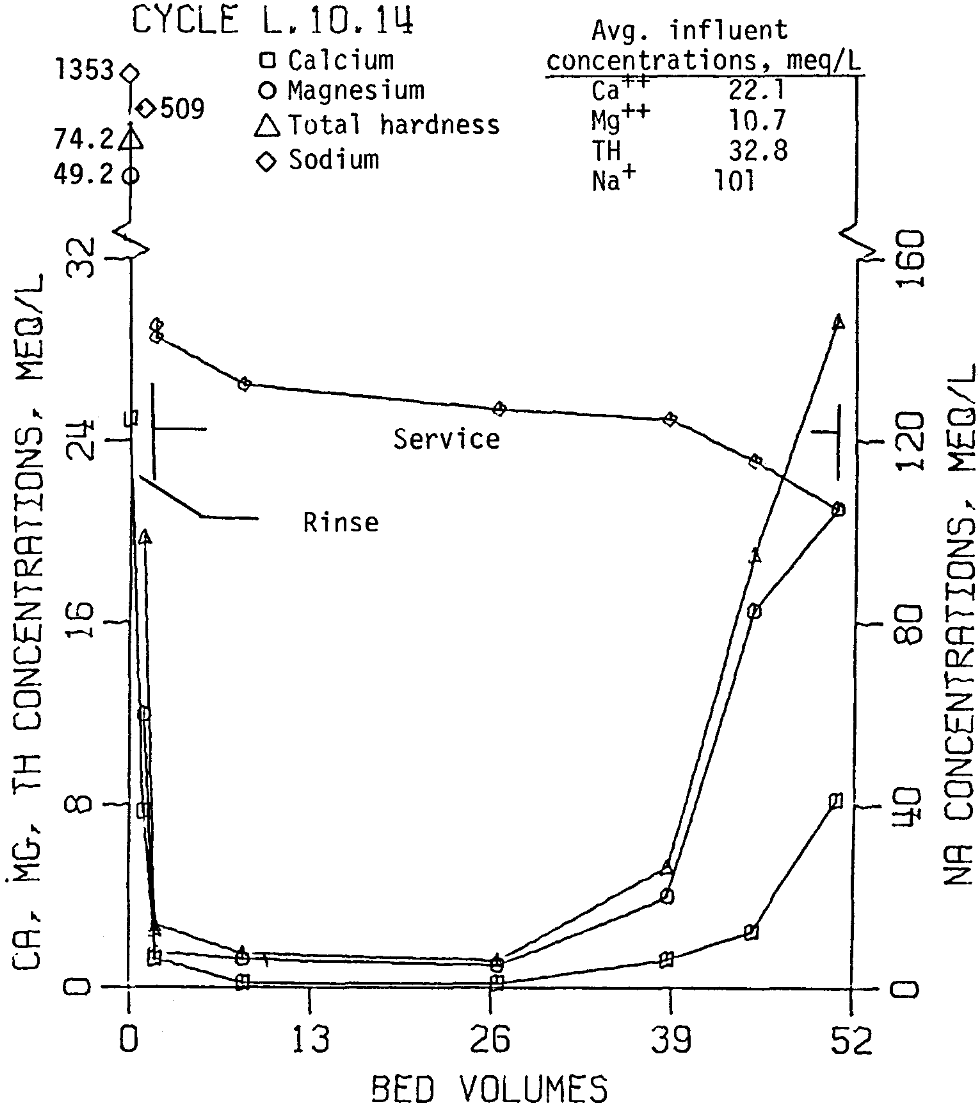
CYCLE L.10.14

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY ~~M~~EQ/L · min
CA	22.12	1.24	20.88	94	1.019	~~.621~~ 3.31
MG	10.70	4.81	5.89	55	.287	~~.175~~ 0.93
TH	32.82	6.05	26.77	82	1.306	~~.797~~ 4.24
NA	101.35	126.19	-24.84			

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.10.14



MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.10.14



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.12.00

Date:	3/14/80
Cycle:	L.12.22
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS-calc.)	-	-
	Fresh regeneration conc. (mg/L TDS-evap.)	-	92 800
	Fresh regeneration flow rate (L/min)	24.0	23.7
	Recycled regenerant flow rate (L/min)	24.0	23.8
	Recycled regenerant volume (L)	1 600	1 610
	Service termination point (meq/L Ca^{++})	6.0	7.8
	Heat exchanger used	Yes	Yes
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes

Standard resin bed: Height[a] = 1 330 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.12.22

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.4	8 800	43.0	90.0	133.0
Spent regenerant (T-6)	7.3	8 800	43.0	89.0	132.0
Lime-softened feed (T-9)	7.2	1 380	21.4	10.0	31.4
Lime-softened feed (T-10)	6.9	1 390	20.6	10.6	31.2
Fresh ED brine (T-28)	6.6	9 920	13.2	43.6	56.8
IX product/ED feed (T-33)	6.5	1 490	1.2	5.0	6.2
Lime-softened feed (clearwell)	7.2	1 380	21.0	10.0	31.0

[a]The resin bed height at the end of drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.12.22

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	230	2.00	23.0	.200	41.	21.6
DRAIN 1	(VENT)	WASTE	2	63	.55	31.6	.275	0.0	
REGEN 2	RE REGEN	SP REGEN	68	1610	14.00	23.8	.207	-1.	26.0
REGEN 3	FR REGEN	SP REGEN	25	601	5.23	23.7	.206	6.8	25.0
RINSE	FEED	WASTE	10	150	1.30	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	201	6030	52.4	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	41	.36	20.7	.180	0.0	
			318						

Fresh Regenerant Volume Balance

Cycle L.12.22

Run L.12.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
16	3/12/80	599	-	5 790	-	90	1.03
17	3/12/80	594	-	5 380	-	90	1.10
18	3/13/80	595	-	5 880	-	90	1.01
19	3/13/80	598	-	5 800	-	90	1.03
20	3/13/80	597	-	5 760	-	90	1.04
21	3/14/80	599	-	5 640	-	90	1.06
22	3/14/80	601	-	6 030	-	90	1.00

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.12.22
(All samples composites except regenerations influent)
(Analysis conducted at Denver on 5/1/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse and service influent	Serivce effluent
pH	units	-	-	-	6.4		8.0	7.4
TDS (calculated)	mg/L	76 220	52 770	72 720	101 020[a]	85 230[a]	8 640	8 210
TDS (evaporated @ 105°C)	mg/L	76 100	53 000	75 200	92 800	89 300	8 570	8 730
Conductivity @ 25°C	mS/m	-	-	-	9 220		1 270	1 270
Silica	mg/L	10.0	8.0	6.0	7.8	10.0	8.0	8.0
Calcium	mg/L	880	3 520	2 080	304	960	416	32.0
Magnesium	mg/L	1 090	1 370	1 070	498	683	137	19.5
Sodium	mg/L	24 500	12 900	21 800	35 300	26 500	2 310	2 310[a]
Potassium	mg/L	1 660	959	1 630	2 340	2 100	217	266
Iron, total	mg/L	0.7	0.4	0.4	0.36	0.3	0.12	0.03
Manganese, total	mg/L	ND	ND	ND	0.06	ND	0.01	ND
Strontium	mg/L	36.8	42.2	43.6	1.8	36.8	4.9	0.2
Bicarbonate	mg/L	79.3	110	134	68.9	79.3	46.4	40.3
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	12 800	10 000	12 900	27 500	20 000	2 060	2 150
Chloride	mg/L	35 200	23 900	33 100	35 000	34 900	3 450	3 380
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	11.0	-	6.8	6.5
E.F. [TDS(evaporated)/cond.]		-	-	-	10.1	-	6.7	6.9
Σ Anions	meq/L	1 260.30	882.80	1 202.20	1 559.13	1 400.30	140.96	140.66
Σ Cations	meq/L	1 236.20	866.50	1 183.60	1 655.80	1 307.70	138.55	111.00
Control value	meq/L	+1.23	+1.18	+0.99	-3.98	+4.25	+1.05	+13.0[a]

[a]Questionable chemical analyses, inconsistent with values on following page and in other IX runs.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.12.22

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	15.97	15.97	31.94	400.17
REGEN 1	EFFLUENT[a]	1.20	239.52	143.37	382.90	900.39
REGEN 2	EFFLUENT[a]	2.00	200.60	143.37	343.97	1000.43
REGEN 2	INFLUENT	5.52	43.91	89.71	133.62	1065.68
REGEN 2	EFFLUENT[a]	9.05	59.88	95.64	155.52	1220.53
REGEN 3	EFFLUENT[a]	16.10	47.90	95.64	143.54	1240.54
REGEN 3	INFLUENT	16.71	15.17	40.99	56.16	1535.45
REGEN 3	EFFLUENT[a]	17.33	47.90	79.67	127.57	1500.65
REGEN 3	EFFLUENT[a]	18.57	39.92	63.70	103.62	1500.65
REGEN 3	EFFLUENT[a]	19.60	31.94	55.80	87.74	1560.68
REGEN 3	EFFLUENT[a]	21.45	31.94	55.80	87.74	1540.67
RINSE	EFFLUENT	0.00	25.55	43.79	69.33	1000.43
RINSE	EFFLUENT	.65	31.94	55.80	87.74	1240.54
RINSE	EFFLUENT	1.30	.80	1.56	2.36	190.08
SERVICE	EFFLUENT	1.30	1.20	.82	2.02	190.09
SERVICE	INFLUENT	4.43	20.76	13.91	34.67	122.05
SERVICE	EFFLUENT	7.57	.80	3.54	4.34	160.07
SERVICE	INFLUENT	25.04	20.76	11.93	32.69	118.05
SERVICE	EFFLUENT	26.35	.90	1.98	2.77	150.07
SERVICE	EFFLUENT	38.87	.80	2.80	3.60	150.07
SERVICE	EFFLUENT	45.13	2.40	15.14	17.54	138.06
SERVICE	EFFLUENT	51.39	5.59	25.51	31.10	122.05
SERVICE	INFLUENT	53.74	20.16	13.83	33.99	120.05
SERVICE	EFFLUENT	53.74	7.78	26.09	33.87	120.05

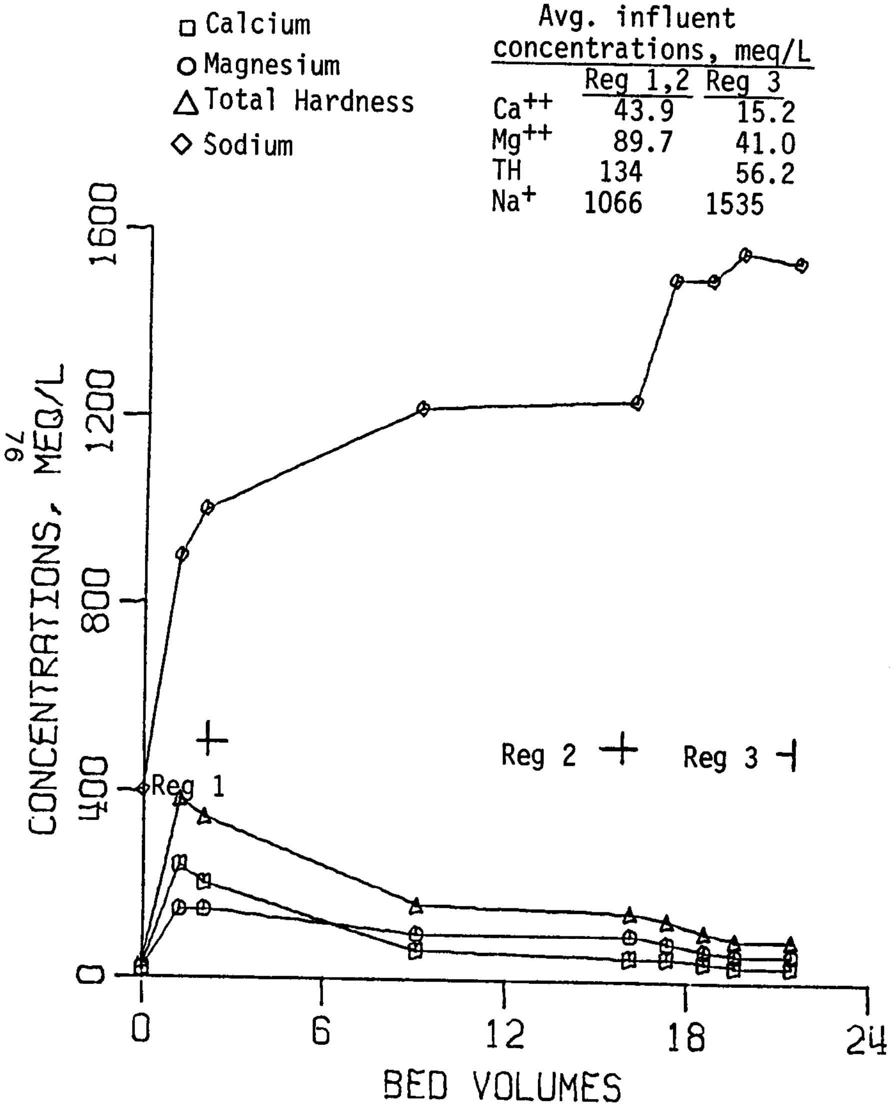
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.

SERVICE PERFORMANCE SUMMARY

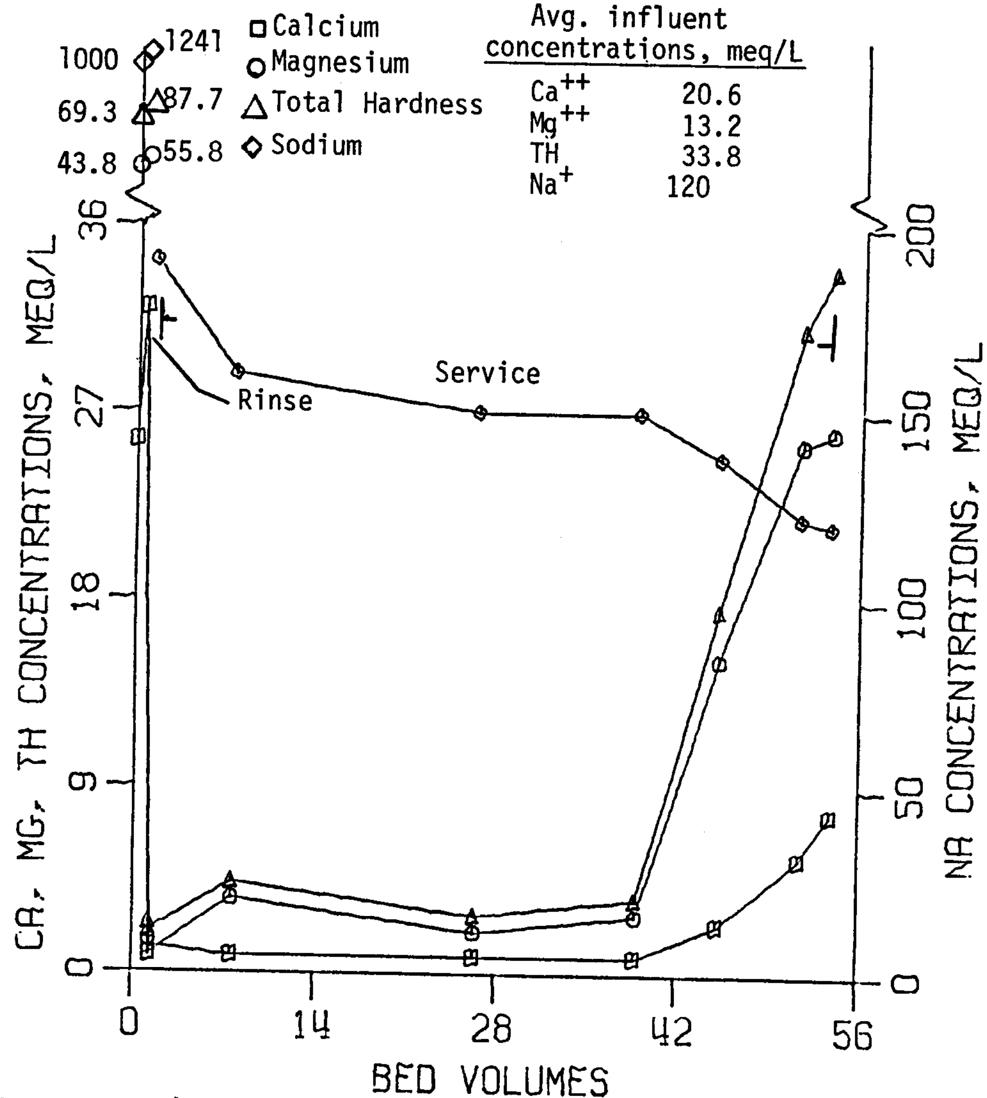
CYCLE L.12.22

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L.MIN
CA	20.56	1.56	19.00	92	.996	~~[illegible]~~ 3.13
MG	13.22	6.47	6.75	51	.354	~~[illegible]~~ 1.11
TH	33.78	8.03	25.75	76	1.350	~~[illegible]~~ 4.24
NA	120.05	150.44	-30.39			

MAJOR CATION CONCENTRATIONS OF IX REGENERATION EFFLUENT CYCLE L.12.22



MAJOR CATION CONCENTRATIONS OF IX RINSE AND SERVICE EFFLUENTS CYCLE L.12.22



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION. TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.17.00

Date:	3/18/80
Cycle:	L.17.17
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS-calc.)	-	88 290
	Fresh regeneration conc. (mg/L TDS-evap.)	-	93 300
	Fresh regeneration flow rate (L/min)	36.0	34.4
	Recycled regenerant flow rate (L/min)	36.0	32.2
	Recycled regenerant volume (L)	1 600	1 602
	Service termination point (meq/L Ca^{++})	6.0	8.0
	Heat exchanger used	Yes	Yes
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes

Standard resin bed: Height[a] = 1 340 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.17.17

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.3	9 000	42.0	87.0	129.0
Spent regenerant (T-6)	7.2	8 890	41.0	86.0	127.0
Lime-softened feed (T-9)	7.2	1 350	21.4	10.4	31.8
Lime-softened feed (T-10)	6.8	1 370	21.2	10.2	31.4
Fresh ED brine (T-28)	6.5	9 700	12.4	18.2	30.6
IX product/ED feed (T-33)	6.4	1 480	0.8	5.8	6.6
Lime-softened feed (clearwell)	7.2	1 350	21.4	10.2	31.6

[a] The resin bed height at the end of the drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.17.17

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	241	2.10	24.1	.210	40.	21.3
DRAIN 1	(VENT)	WASTE	2	63	.55	31.6	.275	0.0	
REGEN 2	RE REGEN	SP REGEN	50	1602	13.93	32.2	.280	2.	26.1
REGEN 3	FR REGEN	SP REGEN	16	551	4.79	33.6	.292	5.2	25.7
RINSE	FEED	WASTE	20	300	2.61	15.0	.130	0.0	
SERVICE	FEED	WASTE	196	5880	51.1	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			296						

Fresh Regenerant Volume Balance

Cycle L.17.17

Run L.17.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
06	3/15/80	600	-	5 780	-	90	1.04
07	3/15/80	598	-	5 580	-	90	1.07
08	3/16/80	598	-	5 550	-	90	1.08
09	3/16/80	598	-	5 610	-	90	1.07
10	3/16/80	600	-	5 510	-	90	1.09
11	3/16/80	599	-	5 520	-	90	1.09
12	3/17/80	600	96 040	5 320	9 080	90	1.13
13	3/17/80	579	96 040	5 700	9 080	90	1.02
14	3/17/80	552	96 040	5 630	9 080	90	0.98
15	3/17/80	550	96 040	5 830	9 080	90	0.94
16	3/18/80	553	-	5 580	-	90	0.99
17	3/18/80	551	-	5 880	-	90	0.94

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.17.17
(All samples composites except regenerations influent)
(Analysis conducted at Denver on 5/16/80, reanalysis received on 10/9/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse and service influent	Service effluent
pH	units	–	–	–	7.5	–	7.1	7.2
TDS (calculated)	mg/L	79 140	53 810	79 180	88 290	91 900	8 070[a]	8 720
TDS (evaporated @ 105°C)	mg/L	80 400	59 700	78 900	93 300	90 500	8 740	8 650
Conductivity @ 25°C	mS/m	–	–	–	8 800	–	1 160	1 270
Silica	mg/L	10.0	10.0	10.0	7.2	10.0	7.0	6.8
Calcium	mg/L	800	2 840	2 100	288	800	448	24.0
Magnesium	mg/L	1 070	1 430	1 150	634	878	127	91.9
Sodium	mg/L	25 800	15 600	25 100	29 200[a]	30 900	2 230	2 940
Potassium	mg/L	1 920	1 010	1 810	2 680	2 380	217	271
Iron, total	mg/L	ND	0.3	0.5	0.32	0.3	0.05	0.03
Manganese, total	mg/L	0.1	ND	ND	0.08	ND	ND	ND
Strontium	mg/L	37.4	50.7	45.7	1.95	36.2	5.48	0.26
Bicarbonate	mg/L	140	116	110	78.1	134	43.9	40.9
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	14 700	12 100	14 700	20 000[a]	20 900	1 730[a]	2 060
Chloride	mg/L	34 700	25 300	34 200	35 400	35 900	3 270	3 290
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	10.0	-	7.2	6.9
E.F. [TDS(evaporated)/cond.]		-	-	-	10.6	-	7.5	6.8
Σ Anions	meq/L	1 287.30	966.90	1 270.80	1 413.28	1 448.20	128.72	136.17
Σ Cations	meq/L	1 297.10	1 022.90	1 335.70	1 404.90	1 512.90	135.15	143.67
Control value	meq/L	-0.49	-3.71	-3.28	+0.38	-2.87	-3.06	-3.38

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.17.17

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	15.97	39.51	55.47	150.07
REGEN 1	EFFLUENT[a]	1.26	239.52	316.05	555.57	800.35
REGEN 2	EFFLUENT[a]	2.10	239.52	237.04	476.56	900.39
REGEN 2	INFLUENT[a]	6.02	39.92	88.07	127.99	1122.23
REGEN 2	EFFLUENT[a]	9.38	11.98[b]	15.80[b]	27.78[b]	1150.50
REGEN 3	EFFLUENT[a]	16.10	5.19[b]	11.85[b]	17.04[b]	1110.48
REGEN 3	INFLUENT	16.70	14.37	52.18	66.55	1270.12
REGEN 3	EFFLUENT[a]	17.30	7.96[b]	15.80[b]	23.79[b]	1350.59
REGEN 3	EFFLUENT[a]	18.50	3.99[b]	19.75[b]	23.75[b]	1400.61
REGEN 3	EFFLUENT[a]	21.19	7.98[b]	15.80[b]	23.79[b]	1500.65
RINSE	EFFLUENT	0.00	15.97	39.51	55.47	545.24
RINSE	EFFLUENT	1.30	.80	.82	1.62	180.08
RINSE	EFFLUENT	2.61	.80	1.15	1.95	140.06
SERVICE	EFFLUENT	2.61	.80	1.56	2.36	140.06
SERVICE	INFLUENT[c]	5.74	23.95	47.41[b]	71.36	150.07[b]
SERVICE	EFFLUENT	8.87	.40	1.15	1.55	145.06
SERVICE	INFLUENT[c]	23.48	23.95	19.75[b]	43.71	110.05
SERVICE	EFFLUENT	24.78	.80	1.56	2.36	140.06
SERVICE	EFFLUENT	43.57	7.98	19.09	27.08	115.05
SERVICE	EFFLUENT	52.17	15.97(5.4)[d]	23.70	39.67	110.05
SERVICE	INFLUENT[c]	53.74	47.90	15.80[b]	63.71	240.10[b]
SERVICE	EFFLUENT	53.74	7.98	43.46	51.44	110.05

[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b]Questionable chemical analysis result.
[c]There appears a discrepancy of the reported concentrations for the service influent samples. A reanalysis was unable to be conducted due to the samples having been discarded.
[d]Concentration obtained at LVSTS using titrametric method.

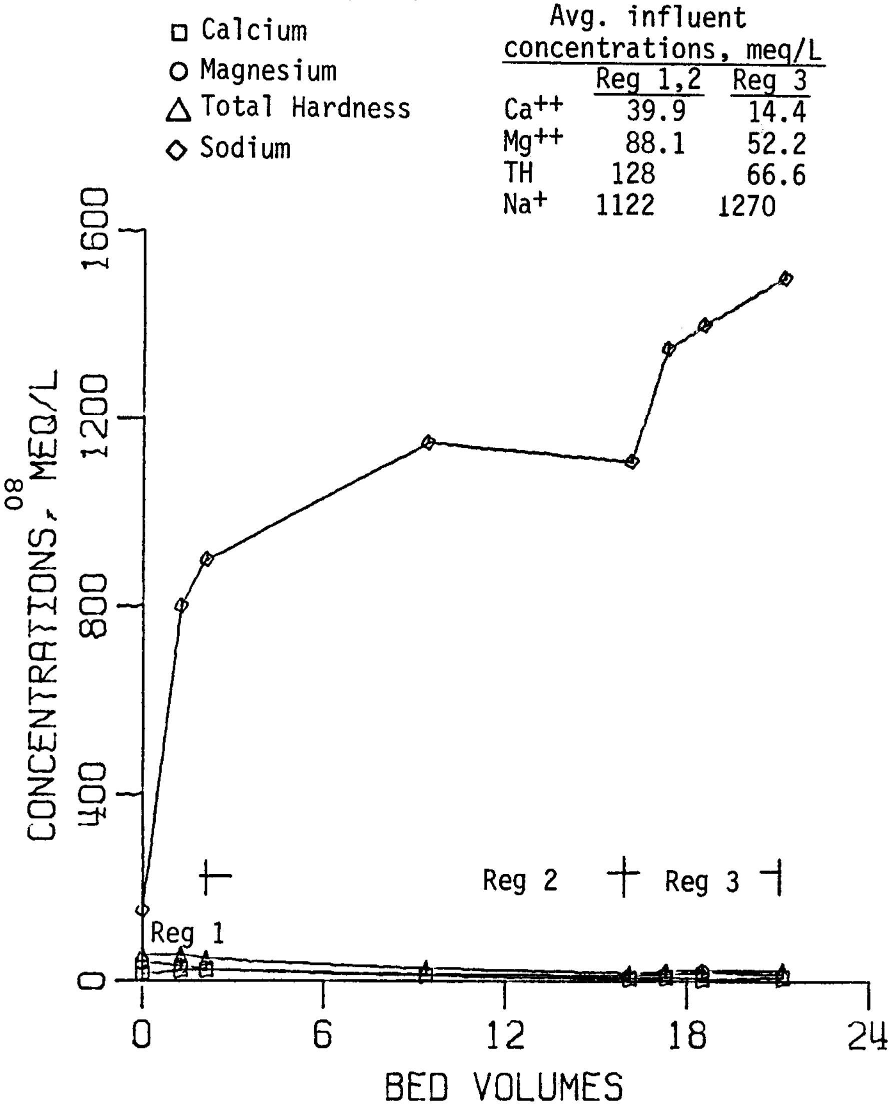
SERVICE PERFORMANCE SUMMARY[a]

CYCLE L.17.17

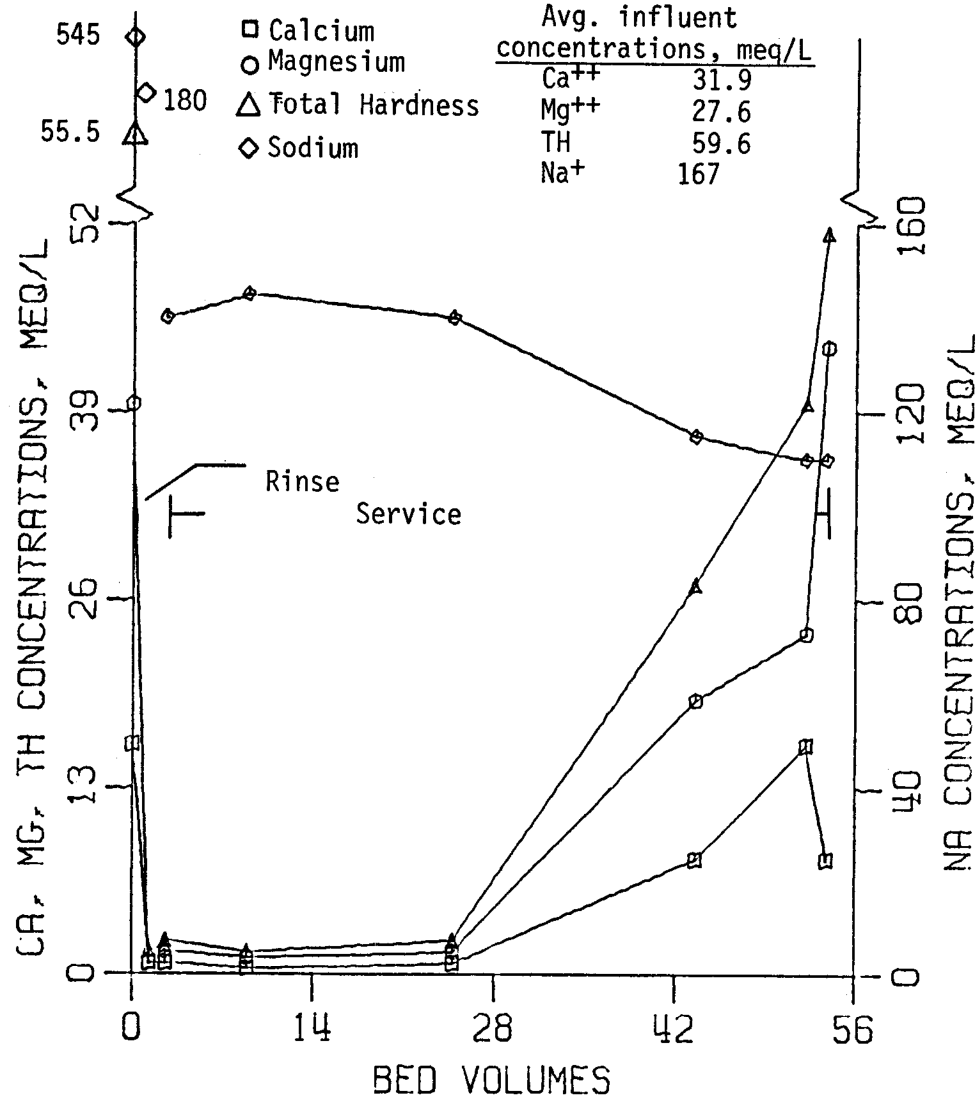
	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY ~~MEQ/L·min/L~~
CA	31.94(22.36)	4.26(1.20)	27.68(21.16)	87(95)	~~1.415 (1.082)~~	~~.934(.718)~~ 3.66
MG	27.65(10.45)	9.01(7.56)	18.64(2.89)	67(28)	~~.953 (.148)~~	~~.623(.098)~~ 0.50
TH	59.59(32.81)	13.27(8.76)	46.32(24.05)	78(73)	2.368 (1.230)	~~1.563(.814)~~ 4.16
NA	166.74(96.96)	131.00(127.83)	35.74(-30.87)			

[a]The time-weighted average service influent and effluent concentrations, and the corresponding resin capacities are in question due to discrepancies of the concentrations of the individual samples. The values in parenthese were calculated using the composite samples rather than summing the individual samples.

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.17.17



MAJOR CATIUN CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.17.17



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.18.00

Date:	3/21/80
Cycle:	L.18.13
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS-calc.)	-	65 780
	Fresh regeneration conc. (mg/L TDS-evap.)	-	91 300
	Fresh regeneration flow rate (L/min)	24.0	23.6
	Recycled regenerant flow rate (L/min)	24.0	23.9
	Recycled regenerant volume (L)	1 600	1 592
	Service termination point (meq/L Ca^{++})	6.0	7.6
	Heat exchanger used	No	No
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes

Standard resin bed: Height[a] = 1 315 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.18.13

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.2	9400	39.0	84.0	123.0
Spent regenerant (T-6)	7.3	9300	39.0	82.0	121.0
Lime-softened feed (T-9)	7.3	1320	22.4	9.6	32.0
Lime-softened feed (T-10)	7.3	1380	21.6	11.4	33.0
Fresh ED brine (T-28)	7.0	9820	11.2	49.6	60.8
IX product/ED feed (T-33)	7.2	1460	1.0	5.4	6.4
Lime-softened feed (clearwell)	7.3	1380	21.2	11.4	32.6

[a]The resin bed height at the end of the drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.18.13

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.09	24.0	.209	42.	18.0
DRAIN 1	(VENT)	WASTE	2	63	.55	31.6	.275	0.0	
REGEN 2	RE REGEN	SP REGEN	66	1592	13.84	24.1	.210	3.	16.0
REGEN 3	FR REGEN	SP REGEN	25	599	5.21	23.6	.205	8.0	17.6
RINSE	FEED	WASTE	20	300	2.61	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	196	5880	51.1	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			321						

Fresh Regenerant Volume Balance

Cycle L.18.13

Run L.18.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_s) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_s$
05	3/19/80	699	-	5 910	-	90	1.18
06	3/19/80	701	-	5 970	-	90	1.17
07	3/19/80	698	-	5 850	-	90	1.19
08	3/20/80	699	-	5 940	-	90	1.18
09	3/20/80	598	-	5 880	-	90	1.02
10	3/20/80	600	-	5 970	-	90	1.00
11	3/20/80	578	-	5 480	-	90	1.05
12	3/21/80	599	-	5 790	-	90	1.03
13	3/21/80	599	-	5 880	-	90	1.02

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.18.13
(All samples composites except regenerations influent)
(Analyzed at Denver on 5/6/80, reanalysis received on 10/9/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse and service influent	Service effluent
pH	units	-	-	-	7.9	-	9.0	9.0
TDS (calculated)	mg/L	80 260	53 870	76 530	65 780[a]	88 350	8 490	8 520
TDS (evaporated @ 105°C)	mg/L	80 800	56 360	80 800	91 300	89 500	8 590	8 650
Conductivity @ 25°C	mS/m	-	-	-	8 980	-	1 320	1 240
Silica	mg/L	7.0	5.0	5.0	1.2[a]	10.0	5.5	5.5
Calcium	mg/L	800	3 840	2 080	560	800	432	32.0
Magnesium	mg/L	488	586[a]	683	1 120	781	97.6	58.6
Sodium	mg/L	26 800	14 100	23 100	22 300[a]	28 700	2 270	2 790
Potassium	mg/L	2 060	1 030	1 860	2 680	2 440	213	213
Iron, total	mg/L	ND	0.2	0.2	0.3	0.4	0.06	0.06
Manganese, total	mg/L	ND	0.2	0.2	0.06	0.1	0.02	0.01
Strontium	mg/L	33.1	47.5	43.4	1.92	31.9	5.19	0.16
Bicarbonate	mg/L	102	106	106	88.5	123	141	129
Carbonate	mg/L	0	0.6	0	0	0	0.6	15.9
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	14 800	10 300	14 500	4 510[a]	20 600	1 910	1 940
Chloride	mg/L	35 200	23 900	34 200	34 500	34 900	3 420	3 340
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	7.3	-	6.4	6.9
E.F. [TDS(evaporated)/cond.]		-	-	-	10.2	-	6.5	7.0
Σ Anions	meq/L	1 302.67	888.76	1 265.74	1 067.45	1 413.02	138.33	137.24
Σ Cations	meq/L	1 302.80	879140	1 217.70	1 156.50	1 416.50	133.66	132.86
Control value	meq/L	-0.01	+0.67	+2.44	-5.35	-0.16	+2.07	+1.96

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.18.13

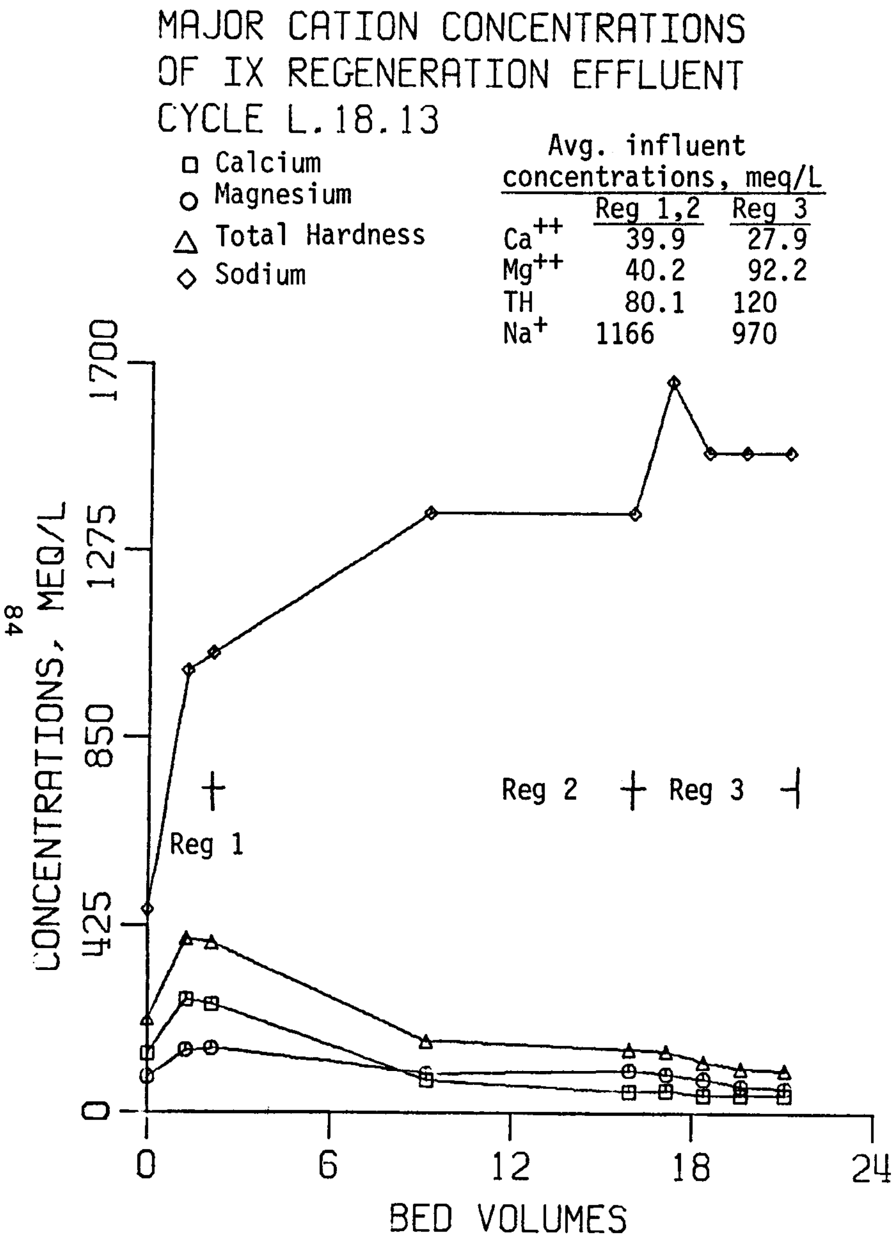
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	129.74	77.70	207.44	460.20
REGEN 1	EFFLUENT[a]	1.25	255.49	139.09	394.58	1000.43
REGEN 2	EFFLUENT[a]	2.09	243.51	143.21	386.72	1040.45
REGEN 2	INFLUENT[a]	5.65	39.92	40.16	80.08	1165.72
REGEN 2	EFFLUENT[a]	9.22	71.86	87.24	159.10	1360.59
REGEN 3	EFFLUENT[a]	15.93	47.90	95.47	143.38	1360.59
REGEN 3	INFLUENT	16.55	27.94	92.18[b]	120.13[b]	969.99[b]
REGEN 3	EFFLUENT[a]	17.16	51.90	87.24	139.14	1660.72
REGEN 3	EFFLUENT[a]	18.39	39.92	75.72	115.64	1500.65
REGEN 3	EFFLUENT[a]	19.62	39.92	59.75	99.67	1500.65
REGEN 3	EFFLUENT[a]	21.06	39.92	55.80	95.72	1500.65
RINSE	EFFLUENT	0.00	20.76	34.24	55.00	900.39
RINSE	EFFLUENT	1.30	.44	.84	1.28	180.06
RINSE	EFFLUENT	2.61	.28	.60	.88	160.07
SERVICE	EFFLUENT	2.61	.40	.48	.88	160.07
SERVICE	INFLUENT	6.00	22.75	9.14	31.89	124.05
SERVICE	EFFLUENT	9.13	.32	.48	.80	124.05[b]
SERVICE	INFLUENT	27.39	22.16	10.37	32.53	210.09
SERVICE	EFFLUENT	28.70	.40	.50	.90	216.62
SERVICE	EFFLUENT	41.74	.60	3.59	4.19	260.11
SERVICE	EFFLUENT	48.26	3.19	20.74	23.93	220.10
SERVICE	INFLUENT	53.74	22.36	9.79	32.15	220.10
SERVICE	EFFLUENT	53.74	7.58	21.32	28.90	300.13

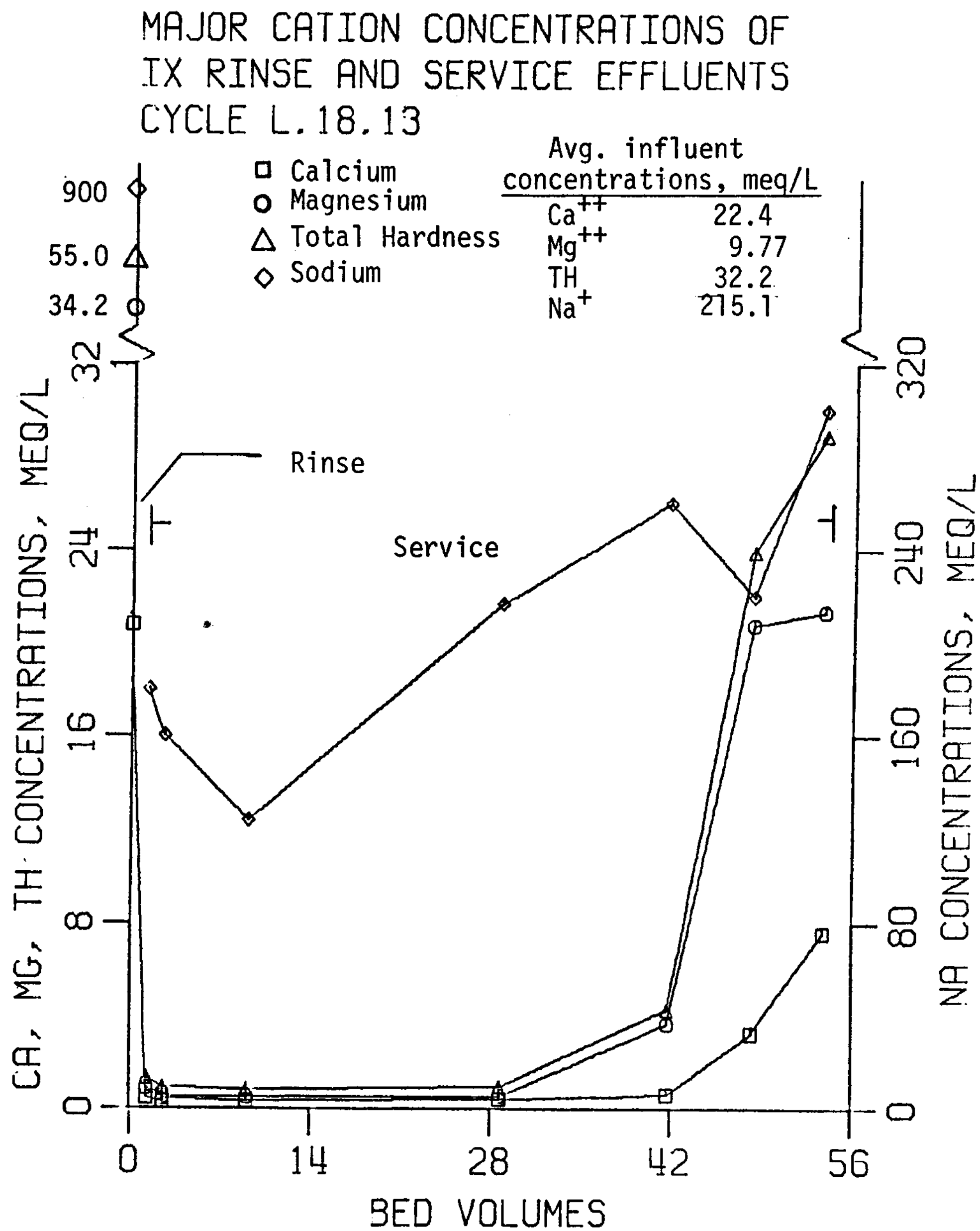
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b]Questionable chemical analysis result.

SERVICE PERFORMANCE SUMMARY

CYCLE L.18.13

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L · min
CA	22.42	1.13	21.29	95	1.089	~~.664~~ 3.39
MG	9.77	4.57	5.19	53	.265	~~.162~~ 0.83
TH	32.19	5.70	26.48	82	1.354	~~.926~~ 4.22
NA	215.1	202.60	-30.35			





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.19.00

Date:	3/27/80		
Cycle:	L.19.27		
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine		
		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS-calc.)	-	91 270
	Fresh regeneration conc. (mg/L TDS-evap.)	-	90 800
	Fresh regeneration flow rate (L/min)	36.0	36.2
	Recycled regenerant flow rate (L/min)	36.0	34.7
	Recycled regenerant volume (L)	1 600	1 597
	Service termination point (meq/L Ca^{++})	6.0	6.8
	Heat exchanger used	No	No
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes
Standard resin bed:	Height[a] = 1 340 mm Volume = 115.0 L		

Chemical Compositions of Tank Waters (Prior to Cycle) L.19.27

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.3	9 410	39.0	86.0	125.0
Spent regenerant (T-6)	7.3	9 360	39.0	87.0	126.0
Lime-softened feed (T-9)	7.2	1 390	21.4	10.4	31.8
Lime-softened feed (T-10)	7.3	1 380	22.0	10.0	32.0
Fresh ED brine (T-28)	6.6	9 900	12.4	43.2	55.6
IX product/ED feed (T-33)	7.0	1 490	0.8	5.0	5.8
Lime-softened feed (clearwell)	7.2	1 370	21.6	10.0	31.6

[a]The resin bed height at the end of the drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.19.27

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	243	2.11	24.3	.211	40.	15.0
DRAIN 1	(VENT)	WASTE	2	40	.35	20.0	.174	0.0	
REGEN 2	RE REGEN	SP REGEN	46	1597	13.89	34.7	.302	8.	12.9
REGEN 3	FR REGEN	SP REGEN	15	551	4.79	36.3	.315	10.	13.6
RINSE	FEED	WASTE	20	300	2.61	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	188	5640	49.0	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			283						

Fresh Regenerant Volume Balance

Cycle L.19.27

Run L.19.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
15	3/24/80	599	-	5 670	-	90	1.06
16	3/24/80	599	-	5 360	-	90	1.12
17	3/24/80	509	-	5 340	-	90	0.95
18	3/25/80	599	94 720	5 490	9 290	90	1.09
19	3/25/80	599	94 720	5 790	9 290	90	1.03
20	3/25/80	63	94 720	4 990	9 290	90	0.13
21	3/25/80	597	94 720	5 460	9 290	90	1.09
22	3/26/80	597	-	5 580	-	90	1.07
23	3/26/80	601	-	5 610	-	90	1.07
24	3/26/80	543	-	5 670	-	90	0.96
25	3/26/80	550	-	5 700	-	90	0.96
26	3/27/80	549	-	5 700	-	90	0.96
27	3/27/80	551	-	5 640	-	90	0.98

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.19.27
(All samples composites except regenerations influent)
(Analyzed at Denver on 5/23/80, reanalyzed on 9/4/80)

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3[a] Influent	Regen 3[a] Effluent	Rinse and service influent	Service effluent
pH	units				7.0		7.7	7.7
TDS (calculated)	mg/L	78 520	58 580	77 240	91 270	62 130[b]	8 480	9 130
TDS (evaporated @ 105°C)	mg/L	80 800	61 000.	79 700	90 800	65 300[b]	8 670	8 610
Conductivity @ 25°C	mS/m				1 260[b]		1 190	1 260
Silica	mg/L	10.0	13.0	9.0	12.0	7.1	9.5	6.3
Calcium	mg/L	800	3 840	2 080	816	1 600	448	23.2
Magnesium	mg/L	1 220	1 730	1 290	859	1 850	120	59.0
Sodium	mg/L	25 300	14 900	23 200	30 900	18 100[b]	2 270	3 090
Potassium	mg/L	1 850	1 070	1 720	2 240	1 230	206	271
Iron, total	mg/L	3.3	3.1	11.8	2.4	1.3	0.3	0.2
Manganese, total	mg/L	0.2	0.2	0.1	0.1	0.2	ND	ND
Strontium	mg/L	43.0	57.0	53.0	30.0	34.5	5.6	0.3
Bicarbonate	mg/L	145	123	140	145	68.9	42.7	40.9
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	14 700	10 900	14 300	21 500	8 270[b]	1 980	1 950
Chloride	mg/L	34 500	26 000	34 500	34 800[b] (37 500)[c]	31 000	3 400	3 690
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	-	9.2	7.1	7.2
E.F. [TDS(evaporated)/cond.]		-	-	-	-	9.7	7.3	6.8
Σ Anions	meq/L	1 280.38	962.02	1 272.29	1 430.38	1 045.13	137.70	145.27
Σ Cations	meq/L	1 287.20	1 009.30	1 264.00	1 508.60	1 050.50	136.06	146.94
Control value	meq/L	-0.34	-3.15[b]	+0.42	-3.51[b]	-0.33	+0.73	-0.71

[a]The influent and effluent compositions were interchanged due to an error in the received analysis.
[b]Questionable chemical analysis result.
[c]Analysis was rerun - value in parenthesis is result from first analysis.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.19.27

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	117.76	83.62	201.39	500.22
REGEN 1	EFFLUENT[a]	1.27	239.52	147.41	386.93	2210.96[b]
REGEN 2	EFFLUENT[a]	2.11	219.56	143.37	362.94	2100.91[b]
REGEN 2	INFLUENT[a]	5.74	39.92	100.41	140.33	1100.48
REGEN 2	EFFLUENT[a]	9.36	67.86	89.63	157.49	1500.65
REGEN 3	EFFLUENT[a]	16.00	49.90	107.57	157.47	1300.57
REGEN 3	INFLUENT	16.63	79.84[b]	152.26[b]	232.10[b]	787.30[b]
REGEN 3	EFFLUENT[a]	17.26	41.92	69.71	111.63	1500.65
REGEN 3	EFFLUENT[a]	18.52	33.93	55.72	89.65	1300.57
REGEN 3	EFFLUENT[a]	19.78	29.04	51.77	81.71	1500.65
REGEN 3	EFFLUENT[a]	20.72	27.04	47.82	75.76	1500.65
RINSE	EFFLUENT	0.00	2.20	3.59	5.78	900.39
RINSE	EFFLUENT	1.30	.40	.80	1.20	170.07
RINSE	EFFLUENT	2.61	.34	.58	.92	160.07
SERVICE	EFFLUENT	2.61	.36	.60	.96	160.07
SERVICE	INFLUENT	5.74	21.96	10.12	32.08	124.05
SERVICE	EFFLUENT	8.87	.32	.56	.88	160.07
SERVICE	INFLUENT	25.09	21.76	10.53	32.29	124.05
SERVICE	EFFLUENT	27.39	.60	.90	1.50	150.07
SERVICE	EFFLUENT	39.91	.80	3.79	4.58	150.07
SERVICE	EFFLUENT	45.39	3.79	18.11	21.90	136.06
SERVICE	INFLUENT	51.65	22.16	9.96	32.11	124.05
SERVICE	EFFLUENT	51.65	6.79	21.32	28.10	130.06

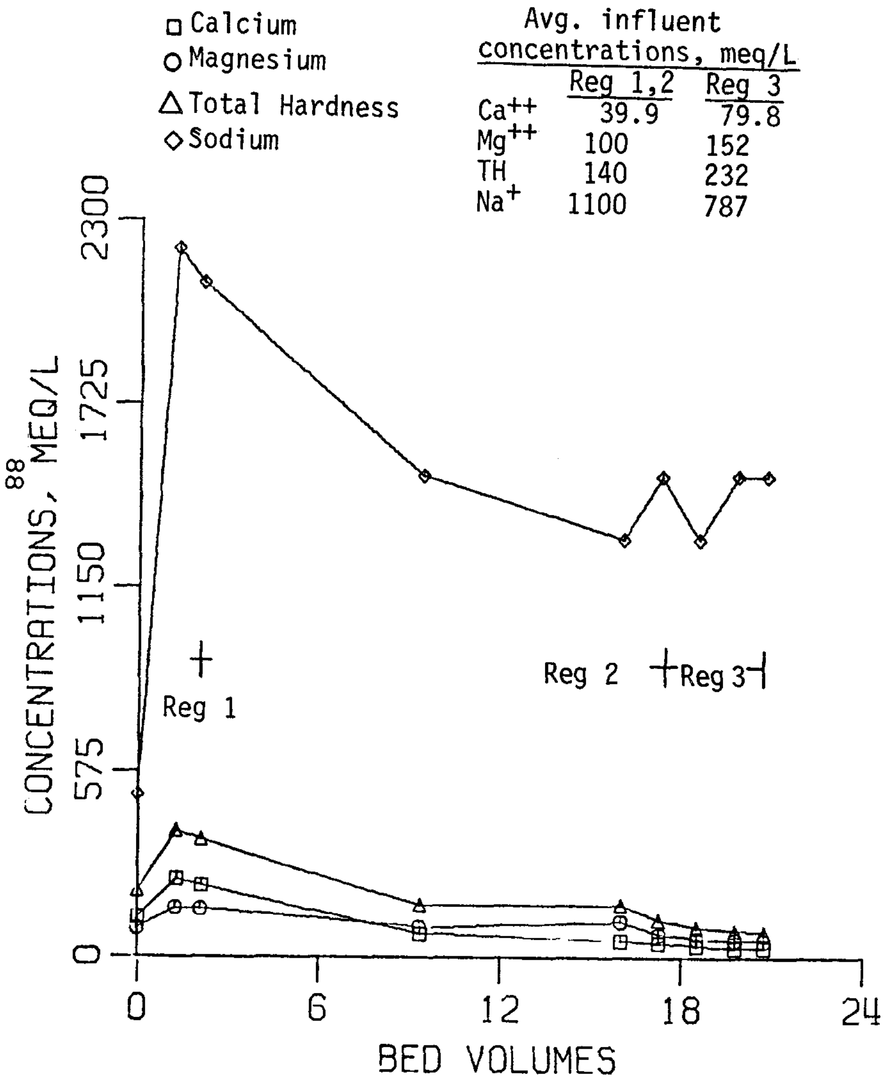
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] Questionable chemical analysis result.

SERVICE PERFORMANCE SUMMARY

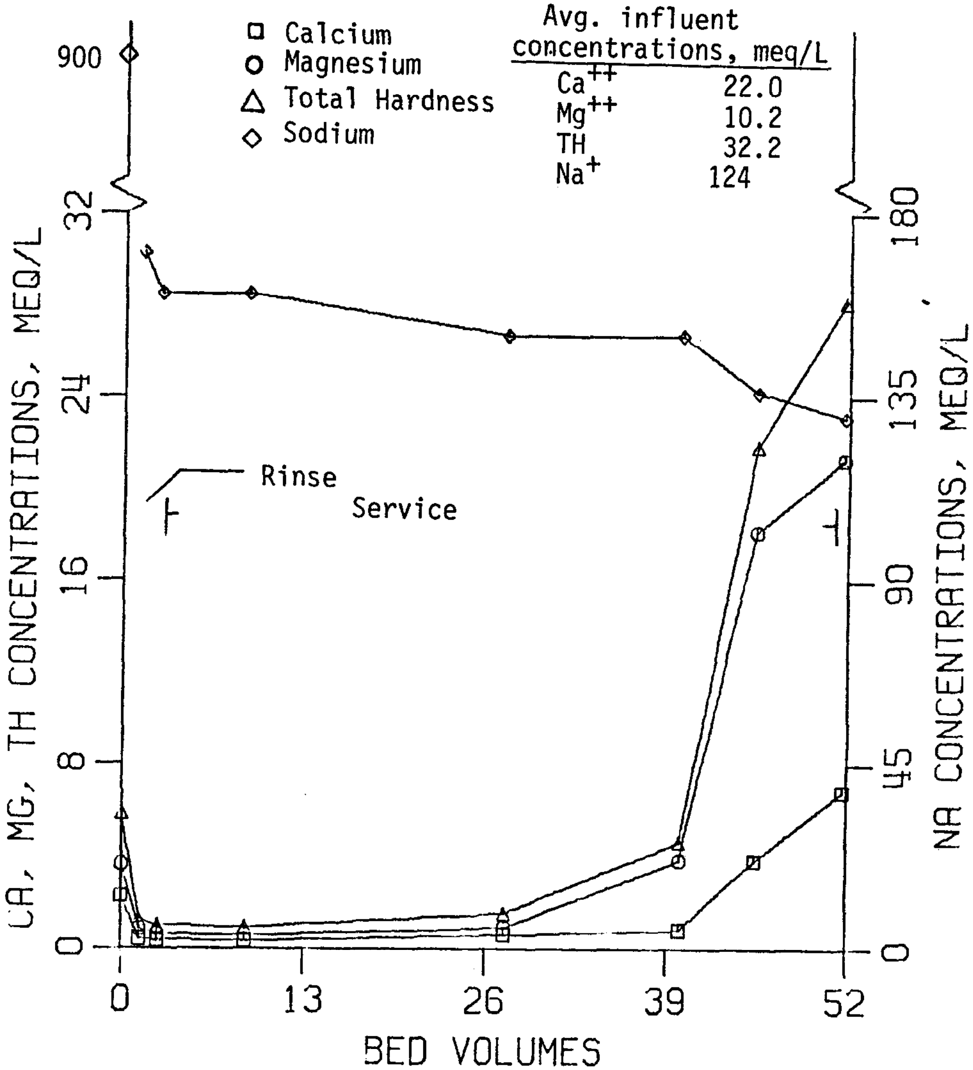
CYCLE L.19.27

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L • min
CA	21.96	1.33	20.63	94	1.012	~~.668~~ 3.58
MG	10.21	4.69	5.52	54	.271	.179 0.96
TH	32.16	6.01	26.15	81	1.282	.846 4.53
NA	124.05	150.28	-26.22			

MAJOR CATION CONCENTRATIONS OF IX REGENERATION EFFLUENT CYCLE L.19.27



MAJOR CATION CONCENTRATIONS OF IX RINSE AND SERVICE EFFLUENTS CYCLE L.19.27



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.20.00

Date: 3/29/80

Cycle: L.20.09

Conditions: Feedwater - LaVerkin Springs - - lime-softened, pretreated
Regenerants - recycled regenerant and fresh ED brine

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS-calc.)	-	87 980
Fresh regeneration conc. (mg/L TDS-evap.)	-	91 900
Fresh regeneration flow rate (L/min)	24.0	23.9
Recycled regenerant flow rate (L/min)	24.0	23.6
Recycled regenerant volume (L)	1 600	1 603
Service termination point (meq/L Ca^{++})	6.0	6.6
Heat exchanger used	No	No
Packed bed regeneration mode used (i.e., resin hold-down)	No	No

Standard resin bed: Height[a] = - mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.20.09

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.3	9 550	43.0	85.0	128.0
Spent regenerant (T-6)	7.2	9 900	37.0	90.0	127.0
Lime-softened feed (T-9)	7.1	1 300	21.6	10.0	31.6
Lime-softened feed (T-10)	7.2	1 380	22.0	9.6	31.6
Fresh ED brine (T-28)	6.7	>10 000	26.0	94.0	120.0
IX product/ED feed (T-33)	6.9	1 300	1.1	4.5	5.6
Lime-softened feed (clearwell)	7.3	1 410	21.8	10.0	31.8

[a]No resin bed height is presented due to no resin bed height for drain 1 being recorded.

OPERATING CONDITIONS

CYCLE L.20.09

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	240	2.09	24.0	.209	*	15.0
REGEN 2	RE REGEN	SP REGEN	68	1603	13.9	23.6	.205	*	11.9
REGEN 3	FR REGEN	SP REGEN	25	598	5.20	23.7	.206	*	13.6
DRAIN 1	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	-
RINSE	FEED	WASTE	10	150	1.30	15.0	.130	0.0	-
SERVICE	FEED	PRODUCT	198	5940	51.7	30.0	.261	0.0	-
DRAIN 2	(VENT)	WASTE	3	41	.36	13.7	.119	0.0	-
			316						

* Top of column, est. 42%

Fresh Regenerant Volume Balance

Cycle L.20.09

Run L.20.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
05	3/28/80	549	-	5 910	-	90	0.93
06	3/28/80	602	-	6 060	-	90	0.99
07	3/28/80	538	-	5 940	-	90	0.91
08	3/29/80	597	-	6 030	-	90	0.99
09	3/29/80	598	-	5 940	-	90	1.01

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.20.09
(All samples composites except regenerations influent)
(Analysis conducted at Denver on 5/23/80, reanalyzed on 9/4/80)

		Regen 1,2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse and service influent	Service effluent
pH	units	-	-	-	7.8	-	7.0	7.1
TDS (calculated)	mg/L	87 180	59 260	84 890	87 980	88 320	8 240	8 270
TDS (evaporated @ 105 °C)	mg/L	84 300	60 300	80 200	91 900	90 000	8 650	8 750
Conductivity @ 25 °C	mS/m	-	-	-	9 180	-	1 190	1 220
Silica	mg/L	12.0	9.0	10.0	6.9	11.0	6.7	7.2
Calcium	mg/L	960	1 760	2 190	256	1 010	432	19.2
Magnesium	mg/L	1 200	1 350	1 440	830	800	132	56.6
Sodium	mg/L	27 900	17 700	25 800	27 900[a] (30 900)[b]	28 400	2 130	2 790
Potassium	mg/L	1 900	1 330	1 740	2 700	2 320	210	289
Iron, total	mg/L	0.5	0.3	0.7	0.7	0.6	0.1	0.1
Manganese, total	mg/L	0.2	0.2	0.2	0.4	0.2	ND	ND
Strontium	mg/L	30.0	29.0	44.0	3.3	29.0	5.0	ND
Bicarbonate	mg/L	113	107	107	87.8	80.5	37.2	38.4
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	14 200	10 900	14 800	22 000 (35 400)[b]	21 000	2 020	1 990
Chloride	mg/L	40 900	26 100	38 800	34 200	34 700	3 270	3 080[a] (3 690)[b]
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS (calculated)/cond.]		-	-	-	9.6	-	6.9	6.8
E.F. [TDS (evaporated)/cond.]		-	-	-	10.0	-	7.3	7.2
Σ Anions	meq/L	1 448.85	962.76	1 398.76	1 422.44	1 417.32	134.81	128.93
Σ Cations	meq/L	1 405.00	1 000.10	1 392.40	1 359.80	1 415.20	130.27	134.00
Control Value	meq/L	+1.94	-2.46	+0.29	+2.83	+0.10	+2.07	-2.41

[a] Questionalbe chemical analysis result.
[b] Analysis rerun - values in parenthesis represent results from initial analysis.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.20.09

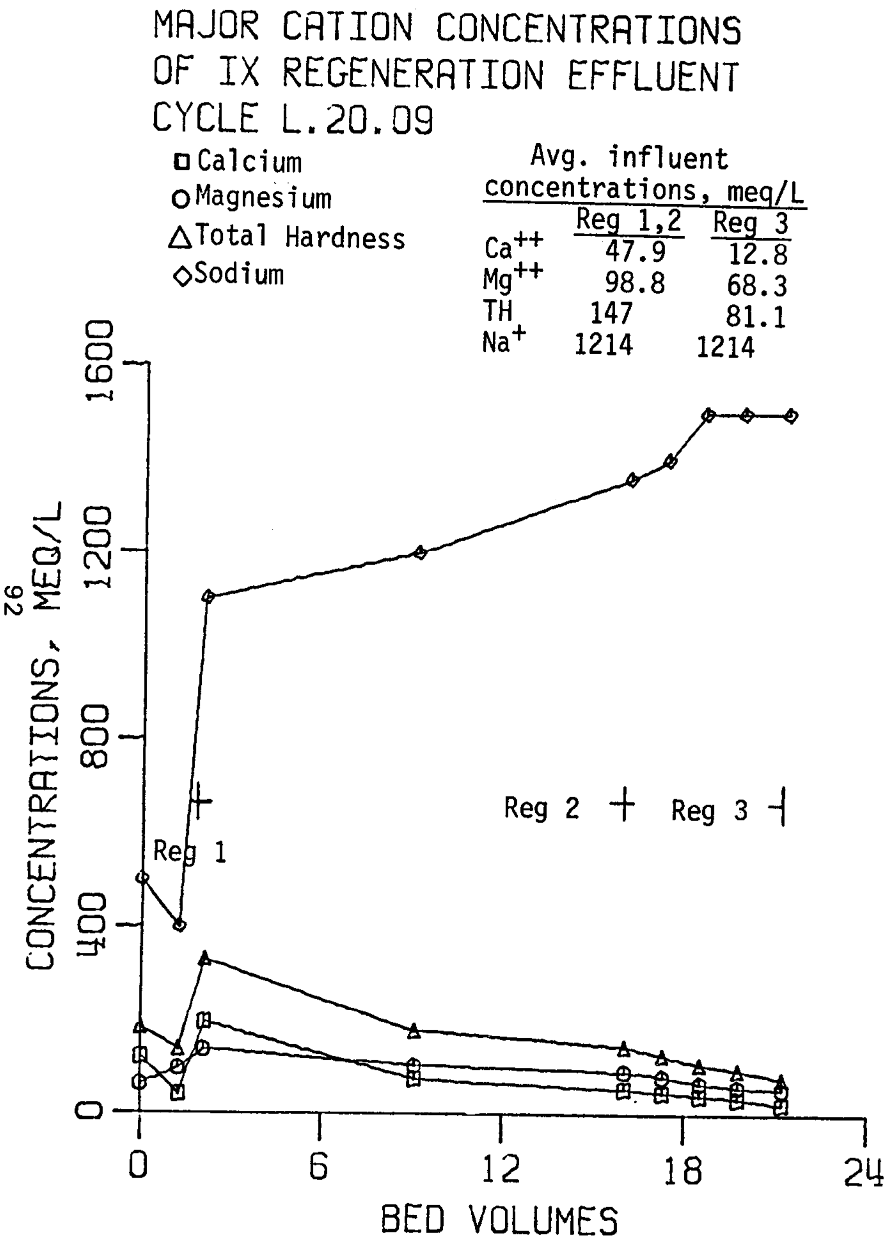
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	119.76	61.73	181.49	500.22
REGEN 1	EFFLUENT[a]	1.25	39.92	95.64	135.56	400.17
REGEN 2	EFFLUENT[a]	2.09	193.61	135.47	329.09	1100.48
REGEN 2	INFLUENT[a]	5.57	47.90	98.77	146.67	1213.57[b]
REGEN 2	EFFLUENT	9.06	73.85	101.56	175.42	1200.52
REGEN 3	EFFLUENT[a]	16.03	53.89	89.63	143.52	1360.54
REGEN 3	INFLUENT[a]	16.65	12.77	68.31	81.09	1213.57
REGEN 3	EFFLUENT[a]	17.27	45.91	79.67	125.58	1400.61
REGEN 3	EFFLUENT[a]	18.52	39.92	65.76	105.68	1500.65
REGEN 3	EFFLUENT[a]	19.77	34.33	58.93	93.26	1500.65
REGEN 3	EFFLUENT[a]	21.22	22.36	54.16	76.51	1500.65
RINSE	EFFLUENT	0.00	27.54	85.05	112.59	1350.59
RINSE	EFFLUENT	.65	30.54	55.17	85.71	1400.61
RINSE	EFFLUENT	1.30	.46	1.28	1.75	170.07
SERVICE	EFFLUENT	1.30	.56	.95	1.51	164.07
SERVICE	INFLUENT	4.70	21.76	11.35	33.11	120.05
SERVICE	EFFLUENT	7.83	.32	.63	.95	150.07
SERVICE	INFLUENT	26.09	21.36	10.95	32.31	116.05
SERVICE	EFFLUENT	27.39	.32	.80	1.12	140.06
SERVICE	EFFLUENT	40.43	.48	3.42	3.90	140.06
SERVICE	EFFLUENT	46.96	2.59	18.72	21.32	120.05
SERVICE	INFLUENT	52.96	21.76	10.56	32.32	116.05
SERVICE	EFFLUENT	52.96	6.59	22.71	29.29	120.05

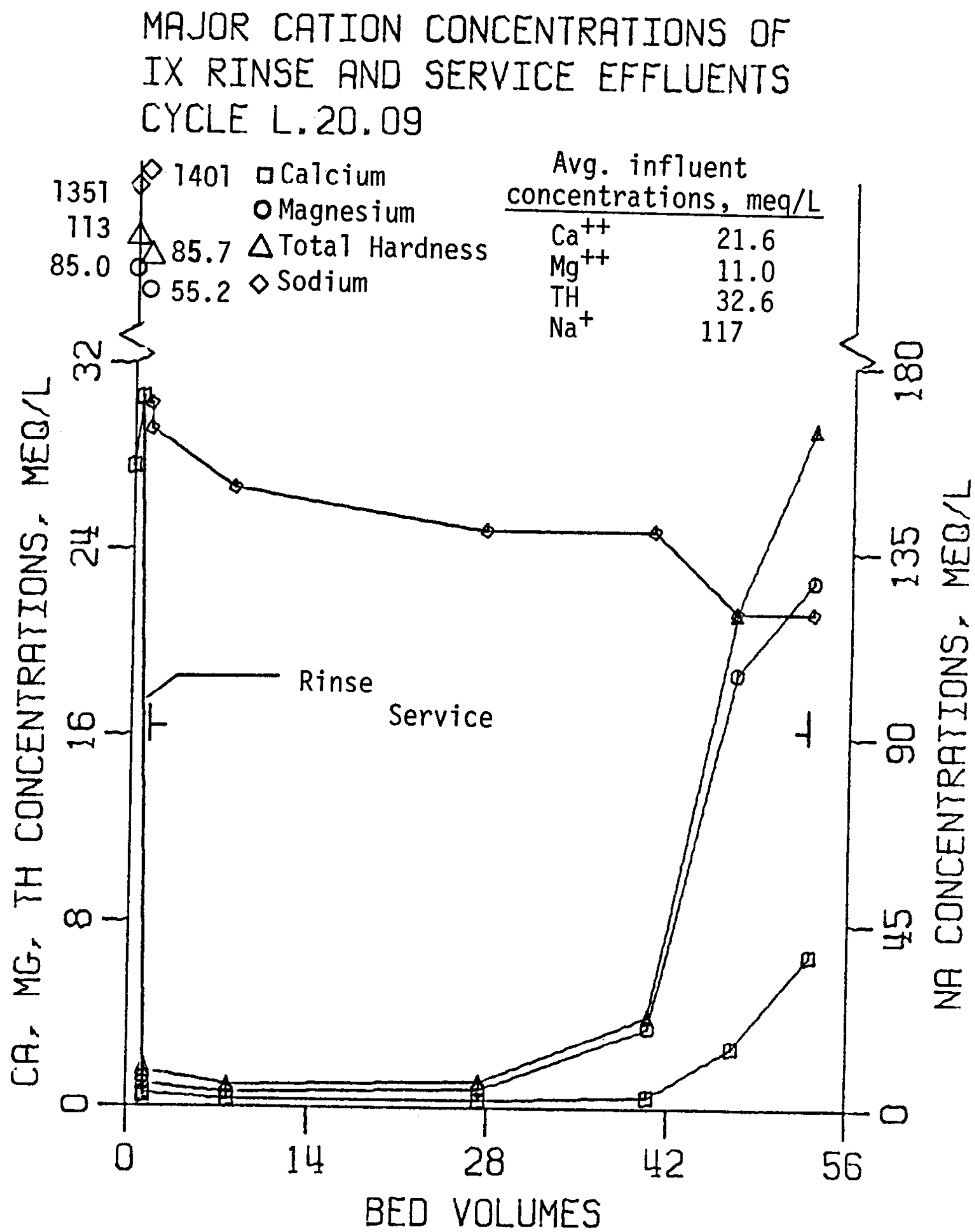
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] Questionable chemical analysis result.

SERVICE PERFORMANCE SUMMARY

CYCLE L.20.09

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L·MIN
CA	21.62	1.00	20.62	95	1.065	~~.671~~ 3.37
MG	10.95	4.71	6.25	57	.323	~~.203~~ 1.02
TH	32.58	5.71	26.86	82	1.398	~~.874~~ 4.39
NA	117.38	140.52	-23.13			





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.22.00

Date:	4/4/80
Cycle:	L.22.15
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS-calc.)	-	90 780
	Fresh regeneration conc. (mg/L TDS-evap.)	-	90 900
	Fresh regeneration flow rate (L/min)	36.0	35.8
	Recycled regenerant flow rate (L/min)	36.0	33.0
	Recycled regenerant volume (L)	800	793
	Service termination point (meq/L Ca^{++})	6.0	7.0
	Heat exchanger used	No	No
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes

Standard resin bed: Height[a] = 1 340 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.22.15

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.5	8 740	42.0	102.0	144.0
Spent regenerant (T-6)	7.4	8 720	42.0	100.0	142.0
Lime-softened feed (T-9)	7.1	1 370	21.0	10.6	31.6
Lime-softened feed (T-10)	7.1	1 390	21.0	10.4	31.4
Fresh ED brine (T-28)	6.7	9 580	13.6	46.4	60.0
IX product/ED feed (T-33)	7.1	1 490	0.8	4.8	5.6
Lime-softened feed (clearwell)	7.1	1 390	21.2	10.4	31.6

[a] The resin bed height at the end of drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.22.15

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RF REGEN	WASTE	10	250	2.17	25.0	.217	40.	15.5
DRAIN 1	FEED	WASTE	2	35	.31	16.0	.139	0.0	
REGEN 2	RF REGEN	SP REGEN	24	793	6.90	33.0	.287	7.1	14.3
REGEN 3	FW REGEN	SP REGEN	14	501	4.36	35.8	.311	8.2	17.5
RINSE	FEED	WASTE	20	290	2.52	14.5	.126	0.0	
SERVICE	FEED	PRODUCT	178	5340	46.4	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			250						

Fresh Regenerant Volume Balance

Cycle L.22.15

Run L.22.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	4/2/80	501	-	5 070	-	90	0.98
05	4/2/80	502	-	4 860	-	90	1.03
06	4/2/80	501	-	5 200	-	90	0.96
07	4/2/80	504	-	4 840	-	90	1.04
08	4/3/80	499	-	4 920	-	90	1.01
09	4/3/80	501	-	5 140	-	90	0.97
10	4/3/80	501	-	5 100	-	90	0.98
11	4/3/80	175	-	4 560	-	90	0.38
12	4/3/80	502	-	5 210	-	90	0.96
13	4/4/80	498	-	5 280	-	90	0.94
14	4/4/80	499	-	5 210	-	90	0.96
15	4/4/80	501	-	5 340	-	90	0.94

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.22.15
(All samples composites except regenerations influent)
(Analysis conducted at Denver on 6/3/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse and service influent	Service effluent
pH	units	-	-	-	7.8	-	7.6	7.7
TDS (calculated)	mg/L	78 690	53 690	72 870	90 780	86 830	8 570	8 630
TDS (evaporated @ 105°C)	mg/L	76 500	56 800	76 200	90 900	89 800	8 840	8 800
Conductivity @ 25°C	mS/m	-	-	-	8 950	-	1 280	1 340
Silica	mg/L	1.0	8.0	8.0	8.0	6.0	4.3	4.7
Calcium	mg/L	1 060	3 560	2 620	310	1 200	436	36.0
Magnesium	mg/L	1 100	1 200	1 470	572	922	127	57.1
Sodium	mg/L	25 100	13 600	21 700	30 100	27 500	2 270	2 950
Potassium	mg/L	1 820	940	1 550	2 820	2 310	206	280
Iron, total	mg/L	0.03	0.3	0.5	0.66	0.7	0.05	0.03
Manganese, total	mg/L	0.01	0.1	0.1	0.07	0.1	0.01	0.01
Strontium	mg/L	2.8	46.0	47.0	4.0	38.0	4.5	ND
Bicarbonate	mg/L	113	86.0	118	68.3	96.4	32.3	32.3
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	12 700	9 000	12 600	22 600	20 600	1 870	2 000
Chloride	mg/L	36 800	25 300	32 800	34 300	34 200	3 620	3 270[a]
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	10.1	-	6.7	6.6
E.F. [TDS(evaporated)/cond.]		-	-	-	10.2	-	6.9	6.4
Σ Anions	meq/L	1 306.85	900.41	1 188.94	1 437.12	1 393.58	141.53	134.23
Σ Cations	meq/L	1 279.40	891.50	1 233.60	1 444.40	1 394.70	136.08	141.65
Control value	meq/L	+1.35	-0.63	-2.41	-0.33	-0.05	+2.37	-3.39

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.22.15

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	105.79	77.70	183.48	440.19
REGEN 1	EFFLUENT[a]	1.30	231.54	143.37	374.91	1000.43
REGEN 2	EFFLUENT[a]	2.17	209.58	143.37	352.96	1100.48
REGEN 2	INFLUENT[a]	3.90	52.89	90.53	143.43	1091.78
REGEN 2	EFFLUENT[a]	5.62	103.79	103.54	207.33	1300.57
REGEN 3	EFFLUENT[a]	9.07	69.96	103.54	173.40	1360.59
REGEN 3	INFLUENT	9.38	15.47	47.08	62.55	1309.26[b]
REGEN 3	EFFLUENT[a]	10.00	69.86	83.62	153.48	1600.70[b]
REGEN 3	EFFLUENT[a]	11.25	53.89	73.66	127.55	1500.65
REGEN 3	EFFLUENT[a]	12.18	45.91	65.76	111.67	1500.65
REGEN 3	EFFLUENT[a]	13.43	45.91	61.73	107.64	1500.65
RINSE	EFFLUENT	0.00	18.95	32.84	51.80	950.41
RINSE	EFFLUENT	1.26	.72	1.43	2.15	180.08
RINSE	EFFLUENT	2.52	.40	.80	1.20	160.07
SERVICE	EFFLUENT	2.52	.48	.72	1.20	160.07
SERVICE	INFLUENT	5.39	21.76	10.95	32.71	120.05
SERVICE	EFFLUENT	8.26	.40	.72	1.12	150.07
SERVICE	INFLUENT	23.91	21.36	11.15	32.51	120.05
SERVICE	EFFLUENT	25.22	.40	.88	1.28	150.07
SERVICE	EFFLUENT	36.70	.64	2.55	3.19	140.06
SERVICE	EFFLUENT	42.43	2.59	16.93	19.52	130.06
SERVICE	EFFLUENT	46.17	6.59	21.91	28.50	120.05
SERVICE	INFLUENT	48.96	24.55	8.36	32.91	120.05
SERVICE	EFFLUENT	48.96	6.99	21.91	28.90	120.05

[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b]Questionable chemical analysis result.

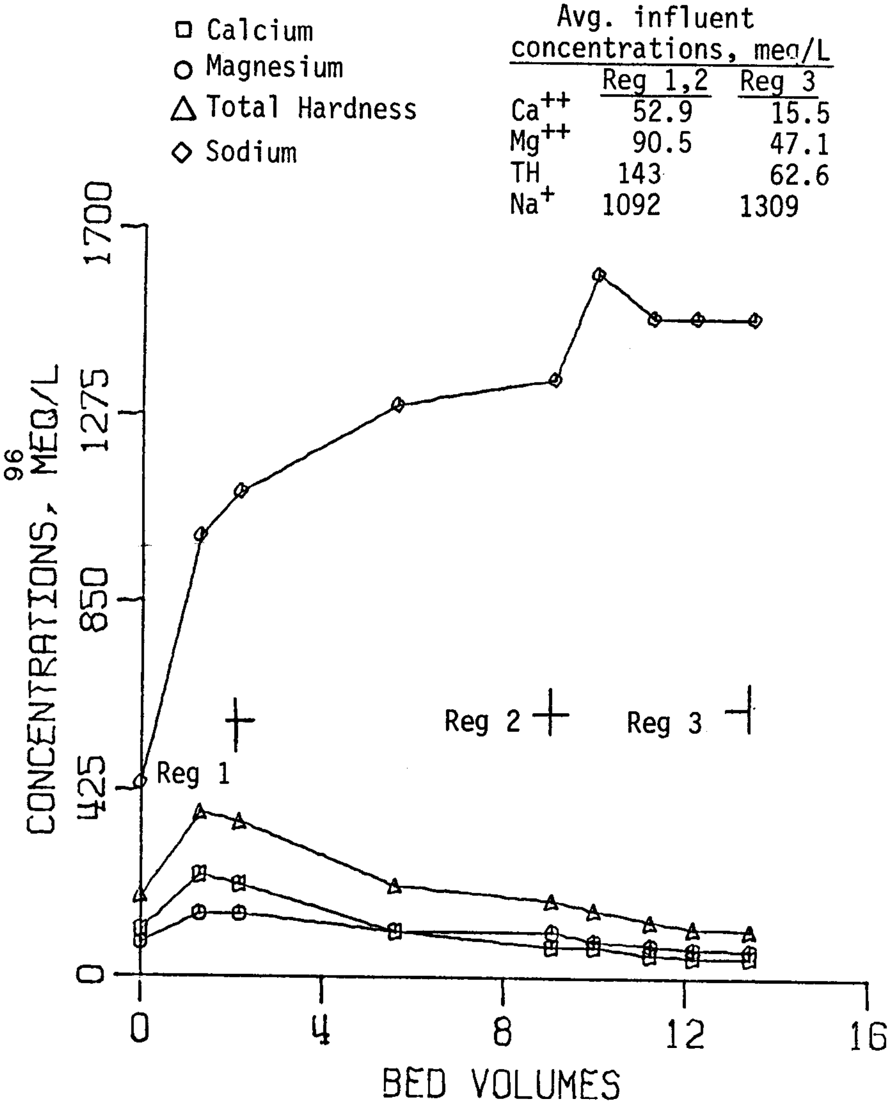
SERVICE PERFORMANCE SUMMARY

CYCLE L.22.15

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY meQ/L · min
CA	22.55	1.21	21.34	95	.991	~~.704~~ 3.96
MG	10.16	4.78	5.38	53	.250	~~.177~~ 1.00
TH	32.71	5.99	26.72	82	1.241	~~.881~~ 4.96
NA	120.05	144.00	-23.94			

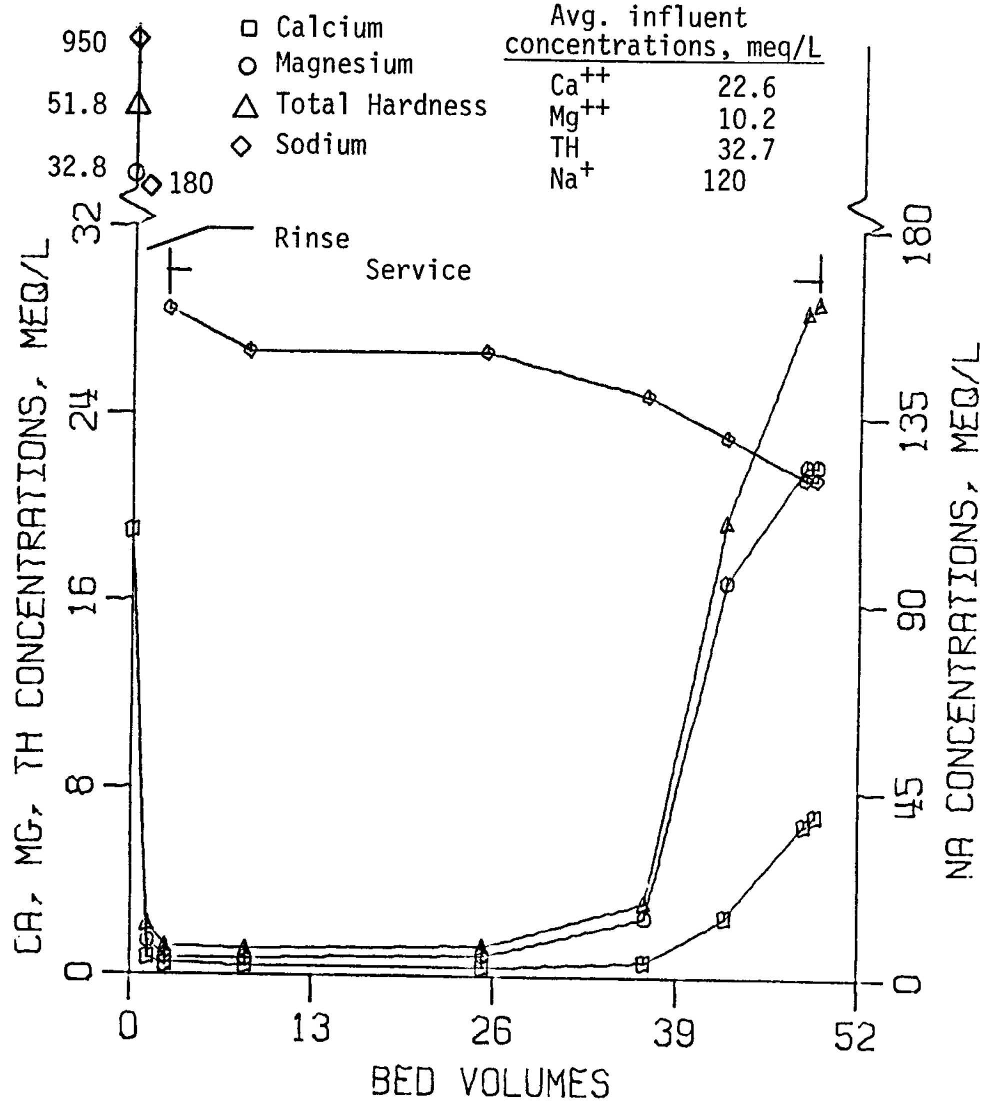
MAJOR CATION CONCENTRATIONS OF IX REGENERATION EFFLUENT CYCLE L.22.15

Avg. influent concentrations, meq/L	Reg 1,2	Reg 3
Ca^{++}	52.9	15.5
Mg^{++}	90.5	47.1
TH	143	62.6
Na^{+}	1092	1309



MAJOR CATION CONCENTRATIONS OF IX RINSE AND SERVICE EFFLUENTS CYCLE L.22.15

Avg. influent concentrations, meq/L	
Ca^{++}	22.6
Mg^{++}	10.2
TH	32.7
Na^{+}	120



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION. TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.23.00

Date: 4/16/80

Cycle: L.23.19

Conditions: Feedwater - LaVerkin Springs - - lime-softened, pretreated
Regenerants - fresh ED brine
Source of backwash - IX feedwater

Control variables:

	Target	Actual
Fresh regeneration conc. (mg/L TDS-calc.)	-	89 270
Fresh regeneration conc. (mg/L TDS-evap.)	-	90 000
Fresh regeneration flow rate (L/min)	24.0	24.0
Recycled regenerant flow rate (L/min)	None	None
Recycled regenerant volume (L)	None	None
Service termination point (meq/L Ca^{++})	6.0	7.0
Heat exchanger used	No	No
Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes
SHMP concentration (mg/L)	100	100

Standard resin bed: Height[a] = 1 300 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.23.19

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.0	1 360	22.4	9.2	31.6
Lime-softened feed (T-10)	7.1	1 360	21.4	10.2	31.6
Fresh ED brine (T-28)	6.2	9 620	14.8	43.2	58.0
IX product/ED feed (T-33)	7.0	1 500	1.2	3.8	5.0
Lime-softened feed (clearwell)	7.1	1 380	21.4	10.2	31.6

[a]The resin bed height at the end of the drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.23.19

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	235	2.04	23.5	.204	33.	28.2
DRAIN 1	(VENT)	WASTE	3	87	.76	29.0	.252	0.0	
REGEN 3	FR REGEN	WASTE	21	500	4.35	24.0	.209	3.8	22.5
RINSE	FEED	WASTE	15	240	2.09	16.0	.139	0.0	
SERVICE	FEED	PRODUCT	177	5310	46.2	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
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Fresh Regenerant Volume Balance

Cycle L.23.19

Run L.23.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
09	4/14/80	599	93 690	5 230	9 160	90	1.15
10	4/14/80	487	93 690	4 930	9 160	90	0.99
11	4/14/80	371	93 690	4 050	9 160	90	0.92
12	4/15/80	512	-	5 220	-	90	0.98
13	4/15/80	508	-	5 070	-	90	1.00
14	4/15/80	500	-	4 920	-	90	1.02
15	4/15/80	500	-	5 280	-	90	0.95
16	4/15/80	500	-	5 500	-	90	0.91
17	4/15/80	501	-	5 310	-	90	0.94
18	4/16/80	502	-	5 220	-	90	0.96
19	4/16/80	500	-	5 310	-	90	0.94

Influent and Effluent Compositions during IX Regeneration and Service - Cycle L.23.19
(All samples composites except regeneration influent)
(Analysis conducted at Denver on 6/20/80)

		Regeneration		Rinse and service	Service
		Influent	Effluent	influent	effluent
pH	units	6.7	-	7.9	7.6
TDS (calculated)	mg/L	89 270	75 890	8 540	9 010
TDS (evaporated @ 105°C)	mg/L	90 000	77 800	8 530	8 570
Conductivity @ 25°C	mS/m	9 220	-	1 250	1 350
Silica	mg/L	-	-	-	-
Calcium	mg/L	512	4 130	451	28.8
Magnesium	mg/L	566	1 290	115	50.8
Sodium	mg/L	29 000	20 600	2 310	2 940
Potassium	mg/L	2 660	1 660	206	276
Iron, total	mg/L	ND	ND	ND	ND
Manganese, total	mg/L	ND	ND	ND	ND
Strontium	mg/L	2.3	47.7	4.8	0.2
Bicarbonate	mg/L	28.1	7.93	9.76	34.8
Carbonate	mg/L	0	0	0	0
Hydroxide	mg/L	-	-	-	-
Sulfate	mg/L	21 800	18 800	1 900	1 700
Chloride	mg/L	33 900	29 400	3 550	3 980[a]
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-
E.F. [TDS(calculated)/cond.]		9.7	-	6.8	6.7
E.F. [TDS(evaporated)/cond.]		9.8	-	6.8	6.3
Σ Anions	meq/L	1411.46	1220.13	139.66	147.97
Σ Cations	meq/L	1440.00	1251.40	138.32	140.66
Control value	meq/L	+0.52	-1.64	+0.59	+3.05[a]

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.23.19

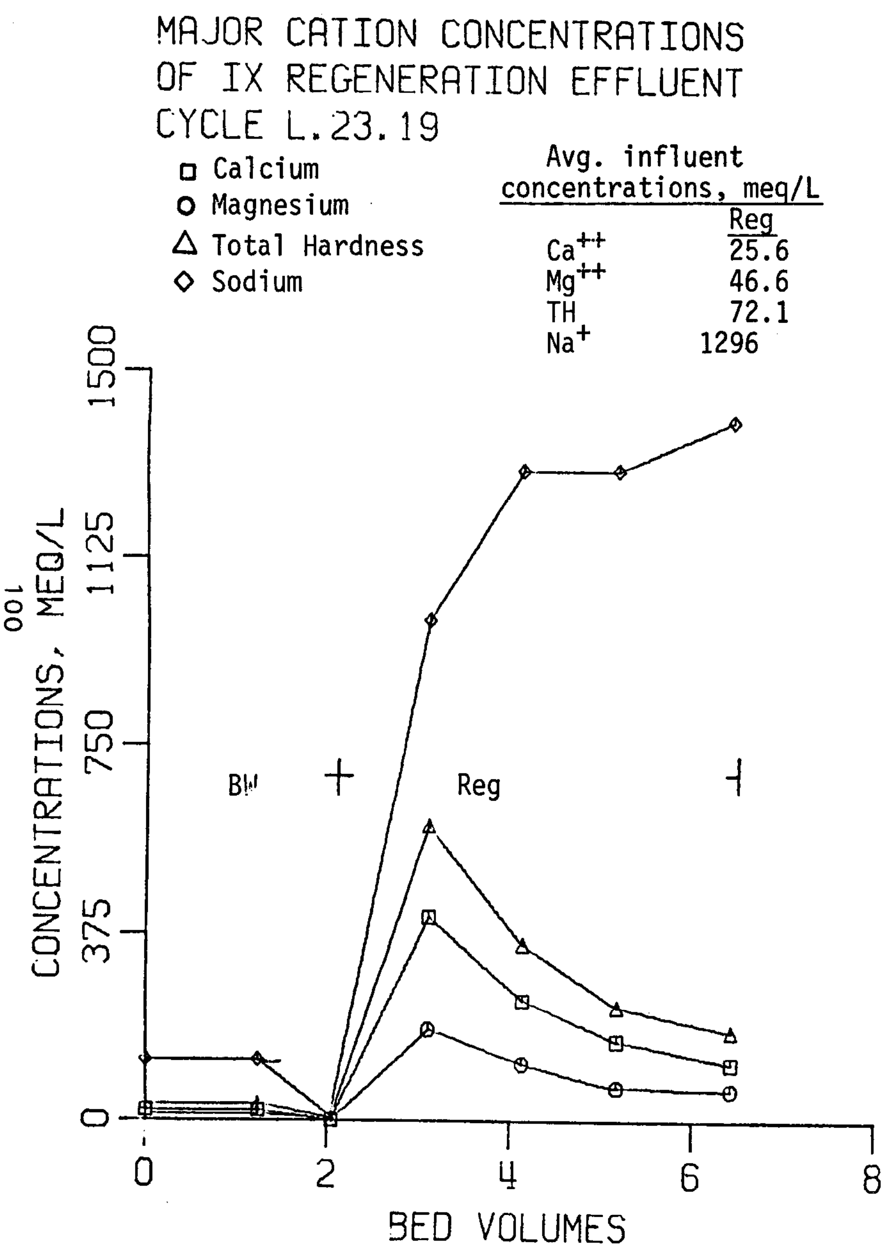
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	21.46	13.17	34.63	121.79
BACKWASH	EFFLUENT	1.23	19.96	13.17	33.13	121.79
REGEN 3	EFFLUENT	2.04	2.00[b]	1.81[b]	3.81[b]	10.00[b]
REGEN 3	INFLUENT	2.46	25.55	46.58	72.13	1296.22
REGEN 3	EFFLUENT[a]	3.09	409.18	181.07	590.25	1000.43
REGEN 3	EFFLUENT[a]	4.13	239.52	115.23	354.75	1300.57
REGEN 3	EFFLUENT[a]	5.17	159.68	67.49	227.17	1300.57
REGEN 3	EFFLUENT[a]	6.43	114.77	62.55	177.32	1400.61
RINSE	EFFLUENT	0.00	219.56[c]	123.46[c]	343.02[c]	2000.87[c]
RINSE	EFFLUENT	.97	1.05	1.07	2.12	170.07
RINSE	EFFLUENT	2.09	.75	.82	1.57	150.07
SERVICE	EFFLUENT	2.09	.70	.76	1.46	160.07
SERVICE	INFLUENT	7.83	22.46	9.88	32.33	120.05
SERVICE	EFFLUENT	13.57	.70	.80	1.50	150.07
SERVICE	INFLUENT	23.74	22.46	9.88	32.33	120.05
SERVICE	EFFLUENT	25.04	.80	.80	1.60	150.07
SERVICE	EFFLUENT	36.78	.90	1.65	2.54	140.06
SERVICE	EFFLUENT	42.52	2.79	13.17	15.96	130.06
SERVICE	INFLUENT	48.26	21.96	10.70	32.66	120.05
SERVICE	EFFLUENT	46.26	6.99	21.40	28.39	120.05

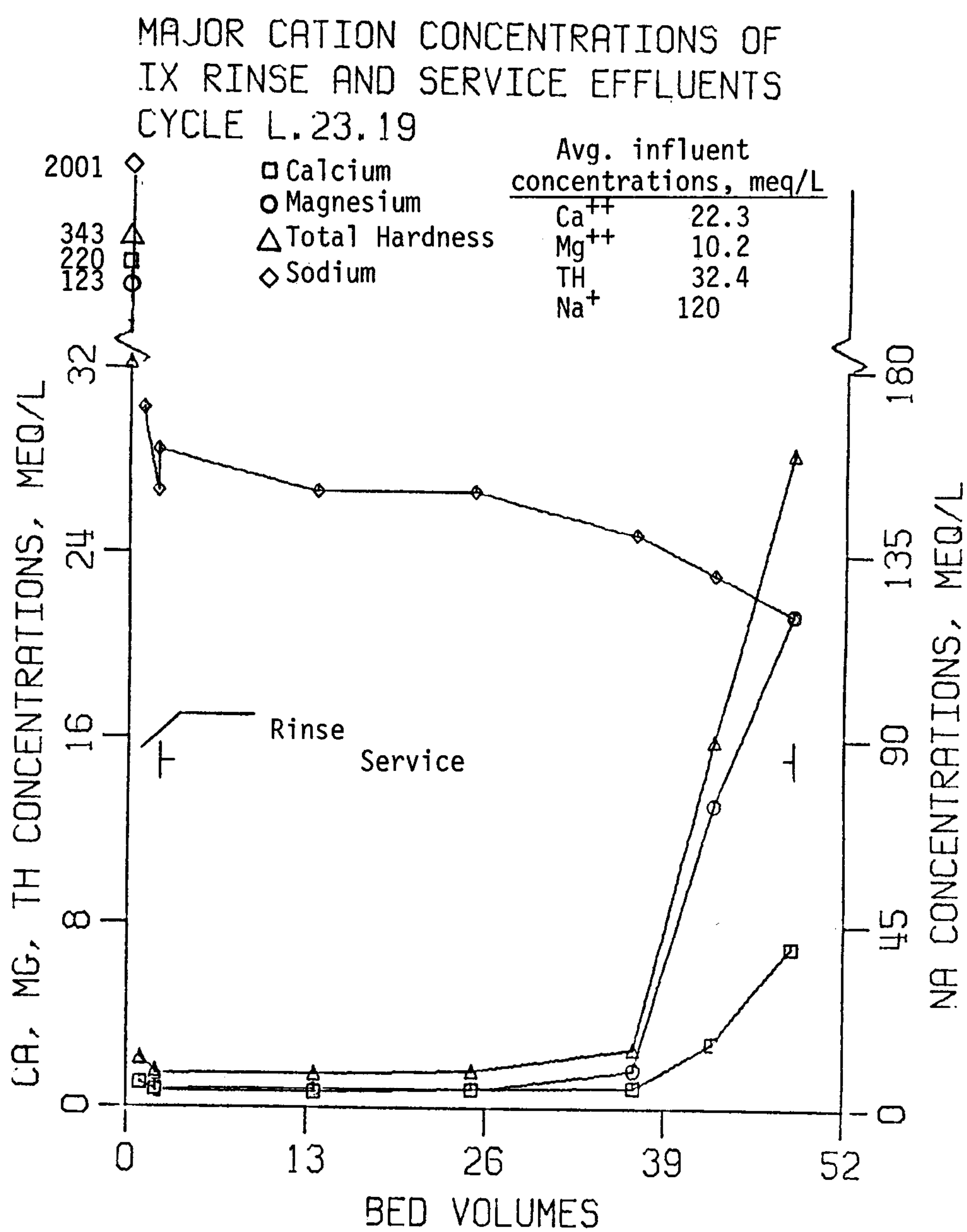
[a]Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b]Apparently values should be multiplied by a factor of ten probably because of sample dilution error.
[c]Values appear erroneous possibly due to some dilution error.

SERVICE PERFORMANCE SUMMARY

CYCLE L.23.19

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY m EQ/L · min
CA	22.29	1.41	20.88	94	.964	~~.752~~ 4.23
MG	10.15	3.77	6.38	63	.295	~~.230~~ 1.29
TH	32.44	5.18	27.26	84	1.258	~~.982~~ 5.52
NA	120.05	145.06	-25.01			





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.24.00

Date:	4/18/80
Cycle:	L.24.11
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - fresh ED brine Source of backwash - IX feedwater

		Target	Actual
Control variables:	Fresh regeneration conc. (mg/L TDS-calc.)	-	84 750
	Fresh regeneration conc. (mg/L TDS-evap.)	-	90 100
	Fresh regeneration flow rate (L/min)	24.0	24.2
	Recycled regenerant flow rate (L/min)	None	None
	Recycled regenerant volume (L)	None	None
	Service termination point (meq/L Ca^{++})	6.0	8.0
	Heat exchanger used	Yes	Yes
	Packed bed regeneration mode used (i.e., resinhold-down)	Yes	Yes
	SHMP concentration (mg/L)	100	100

Standard resin bed: Height[a] = 1 300 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.24.11

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	-	-	-	-	-
Spent regenerant (T-6)	-	-	-	-	-
Lime-softened feed (T-9)	7.0	1 410	21.6	9.8	31.4
Lime-softened feed (T-10)	6.7	1 400	21.2	10.4	31.6
Fresh ED brine (T-28)	5.5	9 720	14.8	40.0	54.8
IX product/ED feed (T-33)	6.0	1 520	1.2	3.8	5.0
Lime-softened feed (clearwell)	7.0	1 390	21.4	9.8	31.2

[a]The resin bed height at the end of drain 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.24.11

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
BACKWASH	FEED	WASTE	10	263	2.29	26.3	.229	31.	30.0
DRAIN 1	(VENT)	WASTE	3	87	.76	29.0	.252	0.0	-
REGEN 3	FR REGEN	WASTE	22	520	4.52	23.2	.202	3.8	29.5
RINSE	FEED	WASTE	15	220	1.91	14.7	.128	0.0	-
SERVICE	FEED	PRODUCT	191	5730	49.8	30.0	.261	0.0	-
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	-
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Fresh Regenerant Volume Balance

Cycle L.24.11

Run L.24.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	4/17/80	537	-	5 180	-	90	1.04
05	4/17/80	541	-	5 620	-	90	0.96
06	4/17/80	541	-	5 610	-	90	0.96
07	4/17/80	541	-	5 550	-	90	0.97
08	4/17/80	538	-	5 700	-	90	0.94
09	4/18/80	540	-	5 590	-	90	0.97
10	4/18/80	540	-	5 550	-	90	0.97
11	4/18/80	540	-	5 730	-	90	0.94

Influent and Effluent Compositions of IX Regeneration and Service - Cycle L.24.11
(All samples composites except regeneration influent)
(Analysis conducted at Denver on 7/11/80)

		Regeneration		Rinse and service	Service
		Influent	Effluent	influent	effluent
pH	units	5.7	-	7.7	7.8
TDS (calculated)	mg/L	84 750	71 090	8 290	8 430
TDS (evaporated @ 105°C)	mg/L	90 100	74 000	8 710	8 700
Conductivity @ 25°C	mS/m	9 220	-	1 270	1 270
Silica	mg/L	5.1	4.0	9.4	10.0
Calcium	mg/L	352	3 680	432	48.0
Magnesium	mg/L	478	1 270	117	68.3
Sodium	mg/L	28 700	19 800	2 270	2 790
Potassium	mg/L	2 300	1 470	188	266
Iron, total	mg/L	ND	ND	ND	ND
Manganese, total	mg/L	ND	ND	ND	ND
Strontium	mg/L	1.9	41.0	4.6	0.2
Bicarbonate	mg/L	15.9	67.1	32.3	32.3
Carbonate	mg/L	0	0	0	0
Hydroxide	mg/L	-	-	-	-
Sulfate	mg/L	21 600	18 100	1 930	1 880
Chloride	mg/L	31 300	26 700	3 310	3 340
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-
E.F. [TDS (calculated)/cond.]		9.2	-	6.5	6.6
E.F. [TDS(evaporated)/cond.]		9.8	-	6.9	6.9
Σ Anions	meq/L	1 332.26	1 129.10	133.93	133.93
Σ Cations	meq/L	1 365.60	1 187.50	134.61	135.80
Control value	meq/L	-1.61	-3.32	-0.31	-0.86

Table

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.24.11

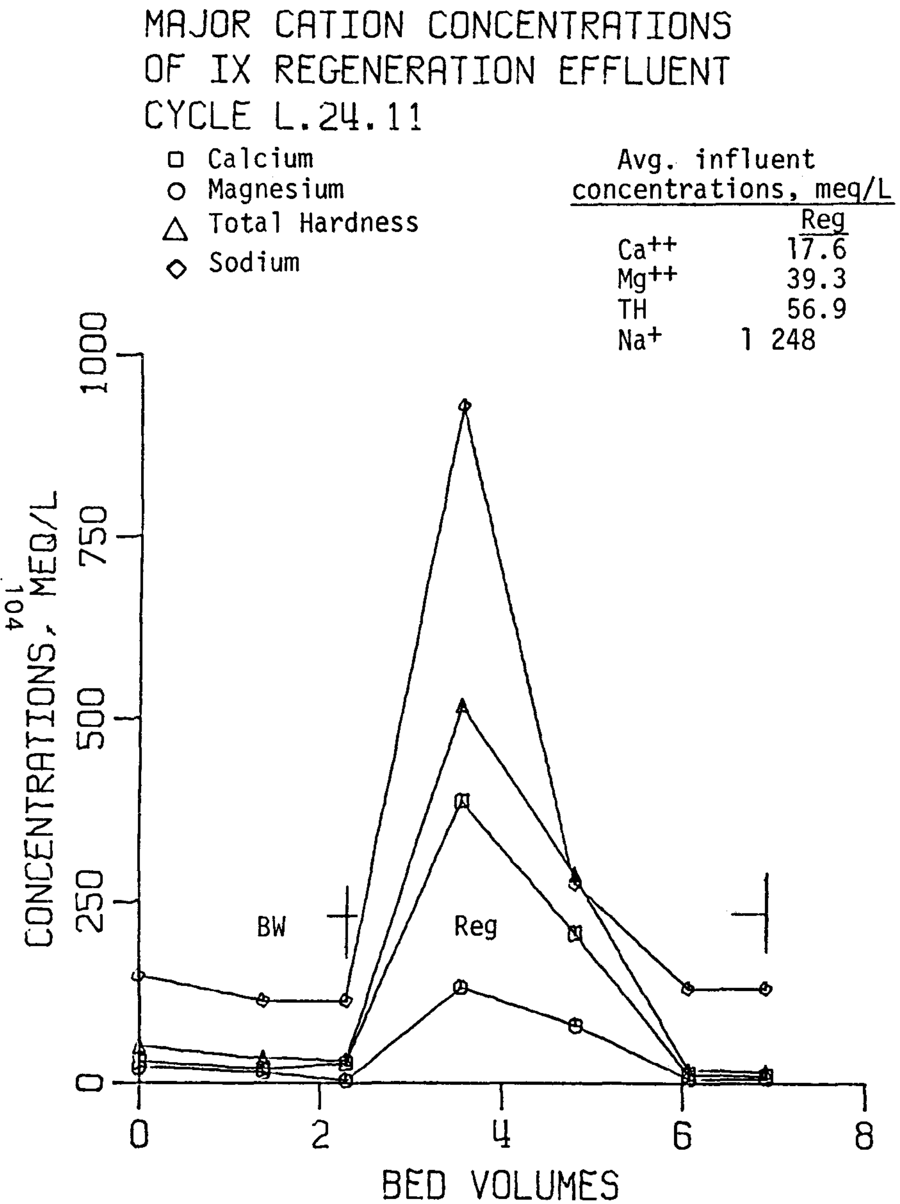
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
BACKWASH	EFFLUENT	0.00	29.94[b]	21.32[b]	51.26[b]	147.89[b]
BACKWASH	EFFLUENT	1.37	19.96	15.23	35.19	113.96
REGEN 3	EFFLUENT	2.29	27.94	4.02	31.96	113.96
REGEN 3	INFLUENT	2.92	17.56	39.34	56.91	1248.37
REGEN 3	EFFLUENT[a]	3.55	387.23	132.51	519.74	930.64
REGEN 3	EFFLUENT[a]	4.81	207.58	80.33	287.91	274.90[b]
REGEN 3	EFFLUENT[a]	6.07	12.77[b]	6.43[b]	19.20[b]	130.93[b]
REGEN 3	EFFLUENT[a]	6.92	10.38[b]	6.43[b]	16.61[b]	130.93[b]
RINSE	EFFLUENT	0.00	25.55	24.94	50.49	543.71
RINSE	EFFLUENT	1.02	1.44	1.60	3.04	210.53
RINSE	EFFLUENT	1.91	1.44	1.45	2.89	158.33
SERVICE	EFFLUENT	1.91	.64	.80	1.44	165.72
SERVICE	INFLUENT	0.00	23.95	9.63	33.58	113.96
SERVICE	INFLUENT	17.22	21.96	11.69	33.64	115.27
SERVICE	EFFLUENT	18.26	.80	1.60	2.40	151.37
SERVICE	EFFLUENT	19.83	1.60	1.60	3.20	137.45
SERVICE	EFFLUENT	34.70	2.40	5.62	8.02	140.93
SERVICE	EFFLUENT	36.52	2.40	13.66	16.06	134.41
SERVICE	INFLUENT	43.83	22.36	9.63	31.98	106.57
SERVICE	EFFLUENT	43.83	7.98	21.73	29.71	103.52

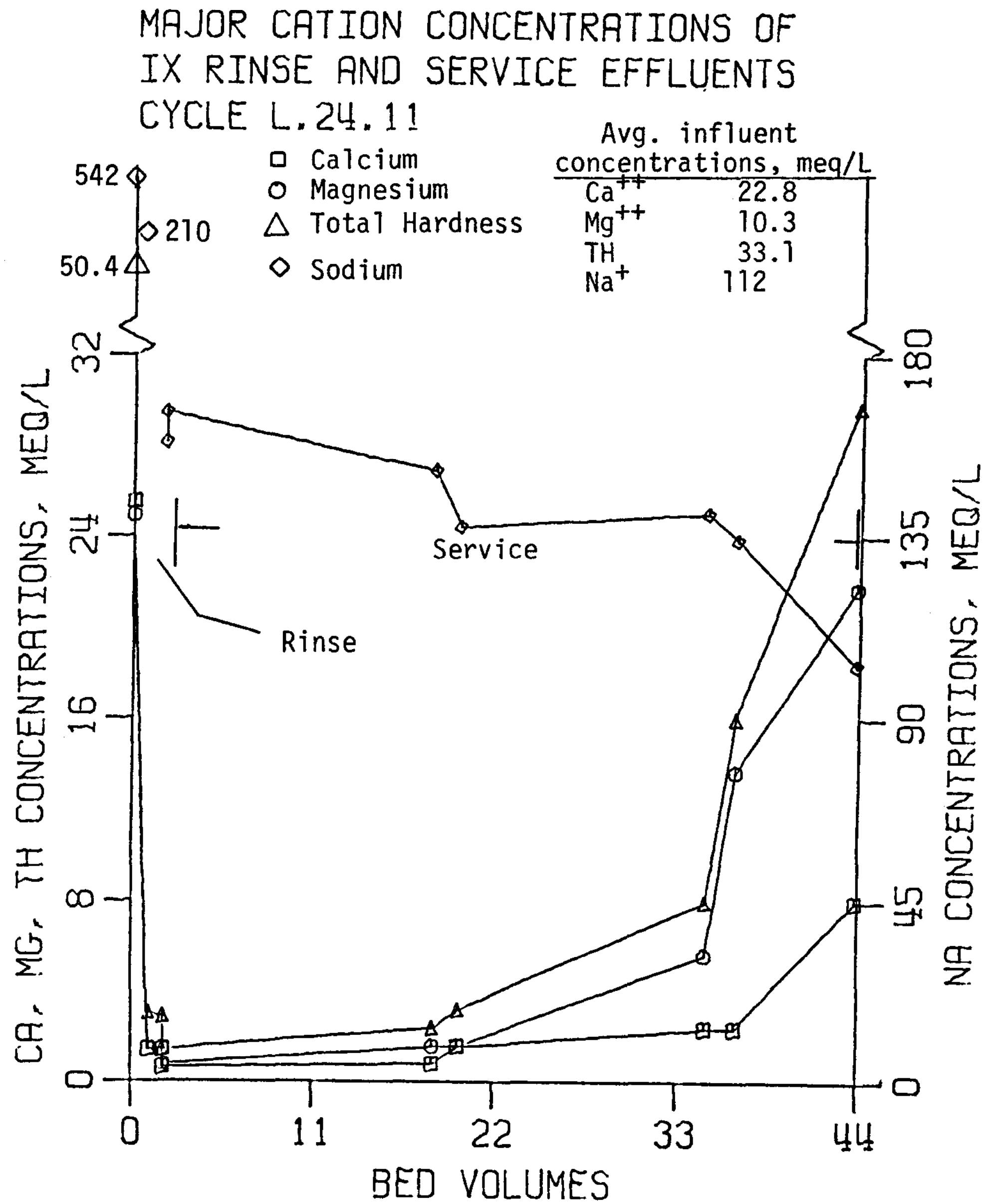
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] Questionable chemical analysis result.

SERVICE PERFORMANCE SUMMARY

CYCLE L.24.11

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY MEQ/L·min	
CA	22.75	~~7.15~~ 2.10	~~15.60~~ 20.66	~~65~~ 91	~~.277~~ ~~.366~~ 1.030	~~.614~~ .691	4.24
MG	10.32	~~7.29~~ 5.79	~~3.02~~ 4.53	~~29~~ 94	~~.151~~ ~~.190~~ 0.222	~~.119~~ .149	0.93
TH	33.07	~~14.45~~ 7.89	~~18.62~~ 25.18	~~56~~ 76	~~.928~~ ~~1.056~~ 1.255	~~.733~~ .830	5.17
NA	111.93	~~139.31~~	~~-27.37~~				





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.25.00

Date: 4/9/80

Cycle: L.25.22

Conditions: Feedwater - LaVerkin Springs - - lime-softened, pretreated
Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual
	Fresh regeneration conc. (mg/L TDS-calc.)	-	95 160
	Fresh regeneration conc. (mg/L TDS-evap.)	-	85 900
	Fresh regeneration flow rate (L/min)	33.0	30.6
	Recycled regenerant flow rate (L/min)	33.0	33.4
	Recycled regenerant volume (L)	800	791
	Service termination point (meq/L Ca^{++})	6.0	7.0
	Heat exchanger used	No	No
	Packed bed regeneration mode used (i.e, resin hold-down)	Yes	Yes

Standard resin bed: Height[a] = 1 410 mm
Volume = 115.0 L

Chemical Compositions of Tank Waters (Prior to Cycle) L.25.22

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	7.3	9 080	41.0	94.0	135.0
Spent regenerant (T-6)	7.2	9 010	42.0	89.0	131.0
Lime-softened feed (T-9)	7.1	1 370	21.6	9.8	31.4
Lime-softened feed (T-10)	7.2	1 380	21.6	9.8	31.4
Fresh ED brine (T-28)	6.2	9 800	13.2	41.2	54.4
IX product/ED feed (T-33)	6.9	1 490	1.6	4.4	6.0
Lime-softened feed (clearwell)	7.2	1 370	21.4	10.2	31.6

[a]The resin bed height at the end of drain-down after Regen 1 was used as the standard resin height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.25.22

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	247	2.15	24.7	.215	33.	19.1
DRAIN 1	(VENT)	WASTE	2	58	.50	29.0	.252	0.0	
REGEN 2	RE REGEN	SP REGEN	24	791	6.88	33.1	.288	.4	17.4
REGEN 3	FR REGEN	SP REGEN	19	575	5.00	30.6	.266	4.6	19.4
UP RINSE	FEED	WASTE	12	385	3.35	32.1	.279	0.0	
DWN RINSE	FEED	WASTE	20	300	2.61	15.0	.130	0.0	
SERVICE	FEED	PRODUCT	193	5800	50.4	30.1	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			282						

[a]Upflow rinse mode.
[b]Downflow rinse mode.

Fresh Regenerant Volume Balance

Cycle L.25.22

Run L.25.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
12	4/7/80	495	-	5 310	-	90	0.93
13	4/7/80	500	-	5 990	-	90	0.83
14	4/7/80	497	-	5 530	-	90	0.90
15	4/8/80	499	-	5 740	-	90	0.87
16	4/8/80	570	-	5 790	-	90	0.98
17	4/8/80	570	-	5 630	-	90	1.01
18	4/8/80	117	-	4 980	-	90	0.23
19	4/8/80	573	-	5 580	-	90	1.03
20	4/9/80	573	-	5 430	-	90	1.06
21	4/9/80	570	-	5 670	-	90	1.01
22	4/9/80	575	-	5 800	-	90	0.99

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.25.22
(All samples composites except regenerations influent)
(Analysis conducted at Denver on 6/20/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & Service influent	Service effluent
pH	units	-	-	-	7.1	-	7.5	7.3
TDS (calculated)	mg/L	74 420	38 110	73 700	95 160	94 660	8 530	8 900
TDS (evaporated @ 105°C)	mg/L	77 400	47 100	75 500	85 900	88 000	8 630	8 440
Conductivity @ 25°C	mS/m	-	-	-	9 220	-	1 270	1 350
Silica	mg/L	0.5	0.5	0.5	6.3	0.5	10.7	11.5
Calcium	mg/L	800	3 070	2 530	800	1 120	432	48.0
Magnesium	mg/L	1 200	1 170	1 390	1 320[a]	781	129	56.6
Sodium	mg/L	23 800	8 860	22 300	30 600	30 100	2 270	2 940
Potassium	mg/L	1 810	778	1 570	1 990	2 150	210	271
Iron, total	mg/L	ND	ND	ND	ND	ND	ND	ND
Manganese, total	mg/L	ND	ND	ND	ND	ND	ND	ND
Strontium	mg/L	27.3	37.8	38.0	-	25.7	4.1	0.3
Bicarbonate	mg/L	11.0	11.0	11.0	42.1	11.0	34.8	34.8
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	13 000	7 820	12 800	27 200	27 100	1 820	1 920
Chloride	mg/L	33 800	16 400	33 100	33 200	33 400	3 620	3 620
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	10.3	-	6.7	6.6
E.F. [TDS(evaporated)/cond.]		-	-	-	9.3	-	6.8	6.3
Σ Anions	meq/L	1 222.18	625.18	1 200.18	1 502.69	1 507.18	140.47	142.57
Σ Cations	meq/L	1 214.70	654.90	1 248.30	1 528.90	1 485.10	136.17	141.98
Control value	meq/L	+0.39	-3.03	-2.57	-1.12	+0.94	+1.88	+0.25

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.25.22

MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	37.92	19.75	57.68	300.13
REGEN 1	EFFLUENT[a]	1.29	234.53	156.38	390.91	1000.43
REGEN 2	EFFLUENT[a]	2.15	214.57	172.84	387.41	1100.48
REGEN 2	INFLUENT[a]	3.87	39.92	98.77	138.69	1035.23
REGEN 2	EFFLUENT[a]	5.60	99.80	98.77	198.57	1300.57
REGEN 3	EFFLUENT[a]	9.05	69.86	90.53	160.40	1300.57
REGEN 3	INFLUENT	9.59	39.92	108.64	148.56	1331.01
REGEN 3	EFFLUENT[a]	10.12	69.86	69.96	139.82	1500.65
REGEN 3	EFFLUENT[a]	11.18	49.90	57.61	107.51	1500.65
REGEN 3	EFFLUENT[a]	12.25	43.91	55.97	99.88	1500.65
REGEN 3	EFFLUENT[a]	14.11	41.92	50.21	92.12	1500.65
UF RINSE[c]	EFFLUENT	1.67[b]	3.39	4.20	7.59	190.08
UF RINSE[c]	EFFLUENT	3.35	2.20	.60	2.80	160.07
DF RINSE[d]	EFFLUENT	3.35	14.47	9.05	23.52	140.06
DF RINSE[d]	EFFLUENT	4.65	2.20	2.39	4.58	160.07
DF RINSE[d]	EFFLUENT	5.96	2.40	1.23	3.63	140.06
SERVICE	EFFLUENT	5.96	1.80	1.81	3.61	150.07
SERVICE	INFLUENT	9.09	21.46	12.35	33.80	120.05
SERVICE	EFFLUENT	11.71	1.60	1.56	3.16	160.07
SERVICE	INFLUENT	28.43	21.96	9.05	31.01	130.06
SERVICE	EFFLUENT	29.74	1.40	1.23	2.63	150.07
SERVICE	EFFLUENT	41.50	1.40	1.23	2.63	150.07
SERVICE	EFFLUENT	47.51	2.79	9.88	12.67	140.06
SERVICE	EFFLUENT	53.52	4.99	20.58	25.57	130.06
SERVICE	INFLUENT	56.39	21.96	11.52	33.48	120.05
SERVICE	EFFLUENT	56.39	6.99	20.58	27.56	130.06

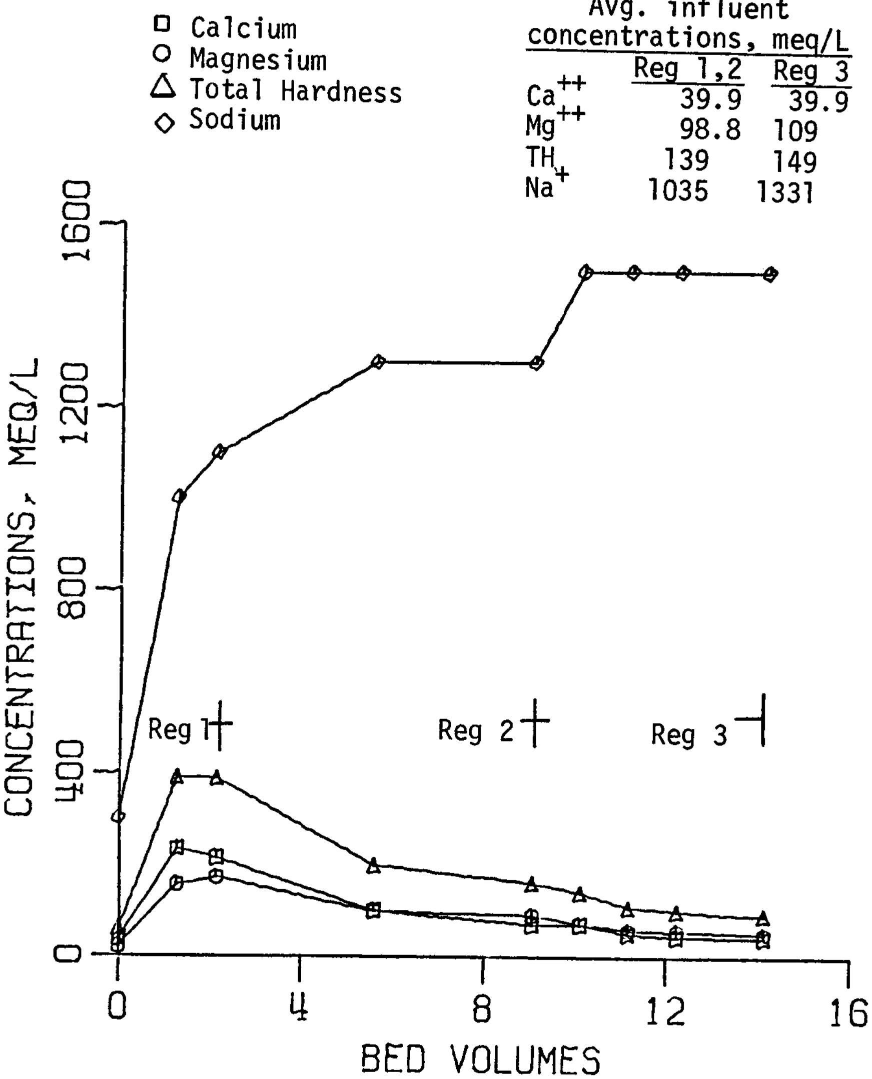
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] No sample of the rinse effluent was collected at the beginning of the mode, therefore the first reported throughput BV is for the sample collected at the midway point of the rinse mode.
[c] Sample collected during upflow rinse.
[d] Sample collected during downflow rinse.

SERVICE PERFORMANCE SUMMARY

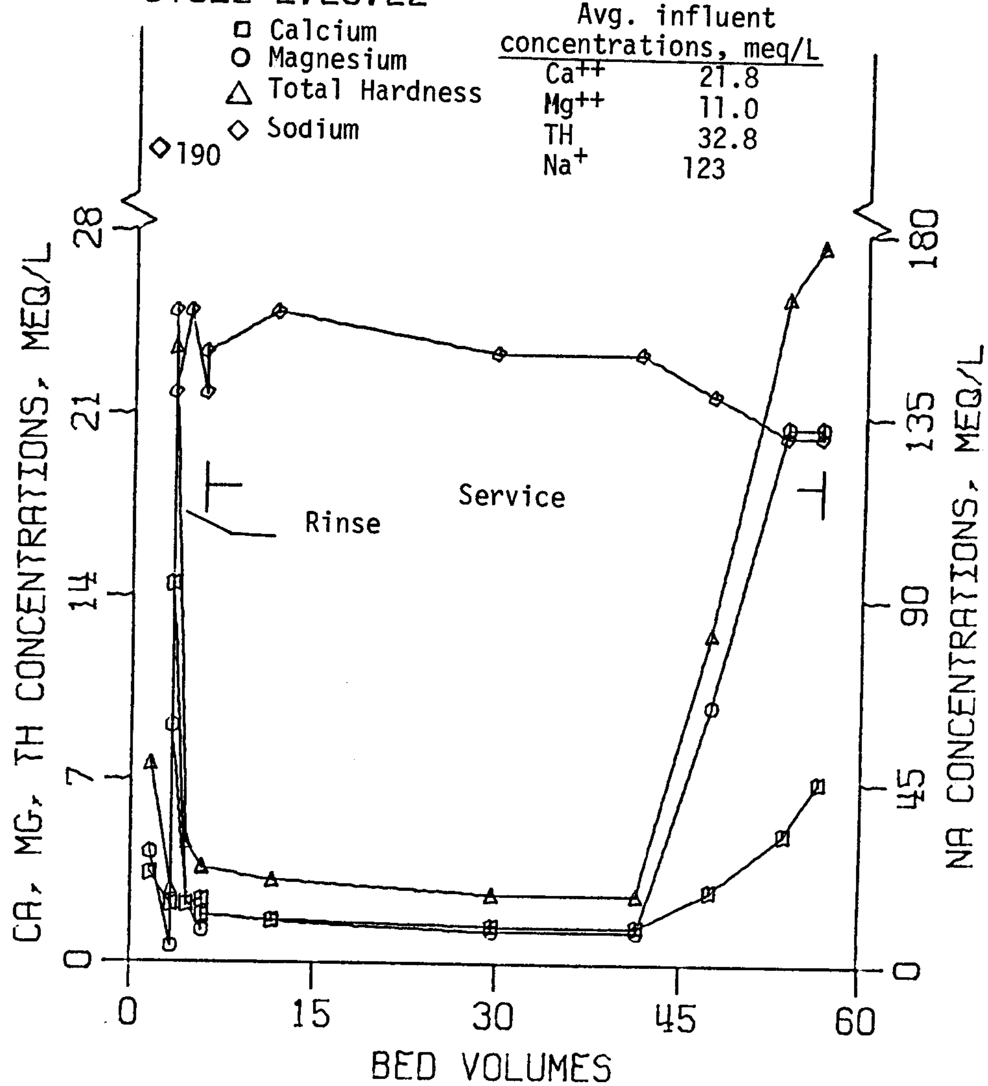
CYCLE L.25.22

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY mEQ/L · min
CA	21.79	2.01	19.78	91	.998	~~.679~~ 3.54
MG	10.97	4.40	6.57	60	.331	~~.225~~ 1.17
TH	32.76	6.41	26.36	80	1.329	.904 4.71
NA	123.39	141.58	-18.19			

MAJOR CATION CONCENTRATIONS
OF IX REGENERATION EFFLUENT
CYCLE L.25.22



MAJOR CATION CONCENTRATIONS OF
IX RINSE AND SERVICE EFFLUENTS
CYCLE L.25.22



SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

Ion-Exchange - Run L.26.00

Date:	4/12/80
Cycle:	L.26.14
Conditions:	Feedwater - LaVerkin Springs - - lime-softened, pretreated Regenerants - recycled regenerant and fresh ED brine

Control variables:		Target	Actual	
	Fresh regeneration conc. (mg/L TDS-calc.)	-	~~95 160~~	91 660
	Fresh regeneration conc. (mg/L TDS-evap.)	-	~~95 000~~	92 800
	Fresh regeneration flow rate (L/min)	33.0	33.2	
	Recycled regenerant flow rate (L/min)	33.0	33.1	
	Recycled regenerant volume (L)	800	798	
	Service termination point (meq/L Ca^{++})	6.0	7.5	
	Heat exchanger used	No	No	
	Packed bed regeneration mode used (i.e., resin hold-down)	Yes	Yes	
Standard resin bed:	Height[a] = 1 330 mm Volume = 115.0 L			

Chemical Compositions of Tank Waters (Prior to Cycle) L.26.14

Tank	pH units	Conductivity mS/m	Ca^{++} meq/L	Mg^{++} meq/L	TH meq/L
Recycle regenerant (T-5)	6.9	9 200	40.0	86.0	126.0
Spent regenerant (T-6)	6.8	9 220	39.0	88.0	127.0
Lime-softened feed (T-9)	7.1	1 410	21.4	10.4	31.8
Lime-softened feed (T-10)	7.0	1 400	21.4	10.4	31.8
Fresh ED brine (T-28)	6.2	9 730	17.6	47.6	65.2
IX product/ED feed (T-33)	6.9	1 550	1.4	4.4	5.8
Lime-softened feed (clearwell)	7.1	1 380	21.8	10.2	32.0

[a]The resin bed height at the end of drain-down after Regen 1 was used as the standard resin bed height in calculating bed expansion.

OPERATING CONDITIONS

CYCLE L.26.14

MODE	INPUT	OUTPUT	DURATION MIN	THROUGHPUT L	VOLUME BV	AVG FLOW RATE L/MIN	AVG FLOW RATE BV/MIN	BED EXPANSION %	TEMPERATURE C
REGEN 1	RE REGEN	WASTE	10	230	2.00	23.0	.200	41.	25.4
DRAIN 1	(VENT)	WASTE	2	49	.43	24.5	.213	0.0	
REGEN 2	RE REGEN	SP REGEN	24	798	6.94	33.1	.288	6.4	16.6
REGEN 3	FR REGEN	SP REGEN	18	601	5.23	33.0	.287	6.0	19.4
DWN RINSE[a]	FEED	WASTE	1	20	.17	20.0	.174	0.0	
UFP RINSE[b]	FEED	WASTE	10	271	2.36	27.1	.236	0.0	
DFP RINSE[c]	FEED	WASTE	10	200	1.74	20.0	.174	0.0	
DWN RINSE[a]	FEED	WASTE	1	20	.17	20.0	.174	0.0	
SERVICE	FEED	PRODUCT	200	6000	52.2	30.0	.261	0.0	
DRAIN 2	(VENT)	WASTE	2	30	.26	15.0	.130	0.0	
			278						

[a]Downflow rinse mode.
[b]Upflow portion rinse of the concurrent upflow/downflow rinse mode.
[c]Downflow portion rinse of the concurrent upflow/downflow rinse mode.

Fresh Regenerant Volume Balance

Cycle L.26.14

Run L.26.00 Cycle no.	Date	Fresh regenerant volume (V_3) L	Fresh regenerant TDS mg/L	Service volume (V_S) L	ED feed TDS mg/L	R %	$V_3/(1-R)V_S$
04	4/10/80	602	-	5 710	-	90	1.05
05	4/10/80	604	-	6 260	-	90	0.96
06	4/10/80	65	-	4 920	-	90	0.13
07	4/11/80	598	-	5 700	-	90	1.05
08	4/11/80	599	-	5 940	-	90	1.01
09	4/11/80	601	-	5 940	-	90	1.01
10	4/11/80	600	-	5 490	-	90	1.09
11	4/11/80	599	-	5 760	-	90	1.04
12	4/12/80	599	-	5 950	-	90	1.01
13	4/12/80	598	-	5 610	-	90	1.07
14	4/12/80	601	-	6 000	-	90	1.00

Influent and Effluent Compositions during IX Regenerations and Service - Cycle L.26.14
(All samples composites except regenerations influent)
(Analyzed at Denver on 6/20/80)

		Regen 1, 2 influent	Regen 1 effluent	Regen 2 effluent	Regen 3 Influent	Regen 3 Effluent	Rinse & Service influent	Service effluent
pH	units	-	-	-	7.1	-	7.5	7.6
TDS (calculated)	mg/L	79 480	45 640	76 200	91 660	100 650[a]	8 430	8 750
TDS (evaporated @ 105°C)	mg/L	77 600	44 000	77 800	92 800	89 100	8 580	8 550
Conductivity @ 25°C	mS/m	-	-	-	9 220	-	1 300	1 350
Silica	mg/L	0.4[a]	0.6[a]	0.4[a]	5.1[a]	0.5[a]	11.0	11.7
Calcium	mg/L	816	2 960	2 640	464	1 120	448	35.2
Magnesium	mg/L	1 160	1 370	1 350	605	947	127	85.9
Sodium	mg/L	25 100	11 100	22 100	30 600[a]	33 200[a]	2 230	2 790
Potassium	mg/L	2 030	794	1 740	2 860	2 420	208	279
Iron, total	mg/L	ND	ND	ND	ND	ND	ND	ND
Manganese, total	mg/L	ND	ND	ND	ND	ND	ND	ND
Strontium	mg/L	2.6	3.5	3.9	2.7	2.5	4.7	0.3
Bicarbonate	mg/L	73.2	67.1	67.1	27.5	67.1	34.8	43.9
Carbonate	mg/L	0	0	0	0	0	0	0
Hydroxide	mg/L	-	-	-	-	-	-	-
Sulfate	mg/L	14 100	7 350	15 600	22 600	19 600	1 890	1 880
Chloride	mg/L	36 200	22 000	32 700	34 500	43 300[a]	3 480	3 620
T-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
P-alkalinity as $CaCO_3$	mg/L	-	-	-	-	-	-	-
T-phosphorus as PO_4	mg/L	-	-	-	-	-	-	-
E.F. [TDS(calculated)/cond.]		-	-	-	9.9	-	6.5	6.5
E.F. [TDS(evaporated)/cond.]		-	-	-	10.1	-	6.6	6.3
Σ Anions	meq/L	1 314.20	774.10	1 245.10	1 443.45	1 629.10	137.97	141.92
Σ Cations	meq/L	1 277.80	762.30	1 247.40	1 475.90	1 635.60	134.93	136.93
Control value	meq/L	+1.78	+0.97	-0.12	-1.44	-0.26	+1.35	+2.16

[a]Questionable chemical analysis result.

MAJOR CATION CONCENTRATIONS OF SAMPLES ANALYZED BY ATOMIC ABSORPTION

CYCLE L.26.14

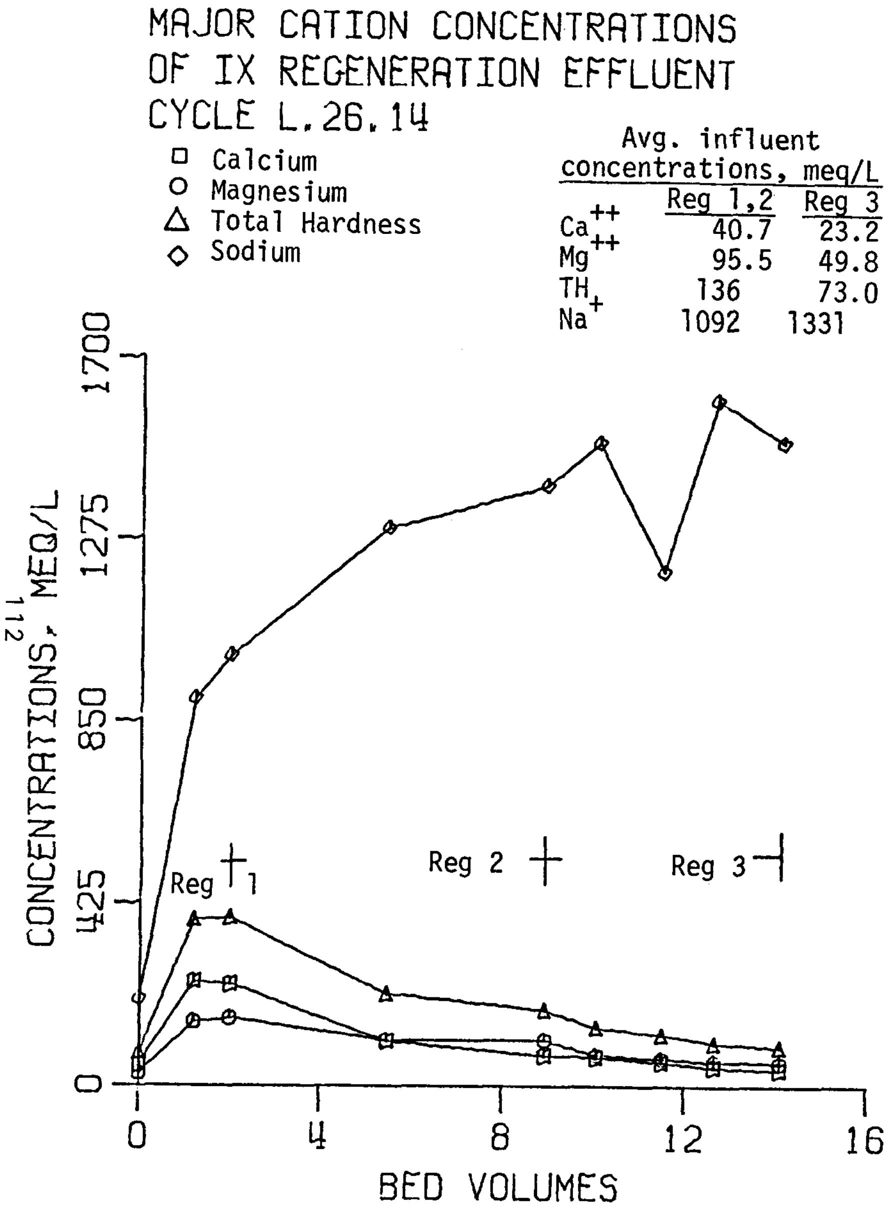
MODE	PROCESS STREAM	THROUGHPUT BV	CA MEQ/L	MG MEQ/L	TH MEQ/L	NA MEQ/L
REGEN 1	EFFLUENT[a]	0.00	49.90	27.16	77.06	200.09
REGEN 1	EFFLUENT[a]	1.20	239.52	148.15	387.67	900.39
REGEN 2	EFFLUENT[a]	2.00	234.53	156.38	390.91	1000.43
REGEN 2	INFLUENT[a]	3.73	40.72	95.47	136.19	1091.78
REGEN 2	EFFLUENT[a]	5.46	104.79	107.00	211.79	1300.57
REGEN 3	EFFLUENT[a]	8.91	69.86	107.00	176.86	1400.61
REGEN 3	INFLUENT	9.49	23.15	49.79	72.95	1331.01[b]
REGEN 3	EFFLUENT[a]	10.07	64.87	71.60	136.48	1500.65
REGEN 3	EFFLUENT[a]	11.51	54.89	64.20	119.09	1200.52[b]
REGEN 3	EFFLUENT[a]	12.66	43.91	56.79	100.70	1600.70
REGEN 3	EFFLUENT[a]	14.11	37.92	53.50	91.42	1500.65
CON RINSE[c]	EFFLUENT	.17	35.93	61.73	97.66	1250.54
CON RINSE[c]	EFFLUENT	2.22	12.97	3.79	16.76	250.11
CON RINSE[c]	EFFLUENT	4.27	3.99	1.81	5.80	160.07
DF RINSE[d]	EFFLUENT	4.44	1.35	2.22	3.57	160.07
SERVICE	EFFLUENT	4.44	1.40	1.56	2.96	160.07
SERVICE	INFLUENT	7.57	22.95	10.70	33.65	120.05
SERVICE	EFFLUENT	11.75	.80	2.55	3.35	160.07
SERVICE	INFLUENT	29.23	22.95	10.70	33.65	120.05
SERVICE	EFFLUENT	30.53	.80	.99	1.79	150.07
SERVICE	EFFLUENT	43.57	1.20	3.54	4.74	140.06
SERVICE	EFFLUENT	50.10	3.29	18.11	21.40	130.06
SERVICE	INFLUENT	56.62	22.46	10.70	33.15	110.05
SERVICE	EFFLUENT	56.62	7.49	22.22	29.71	120.05

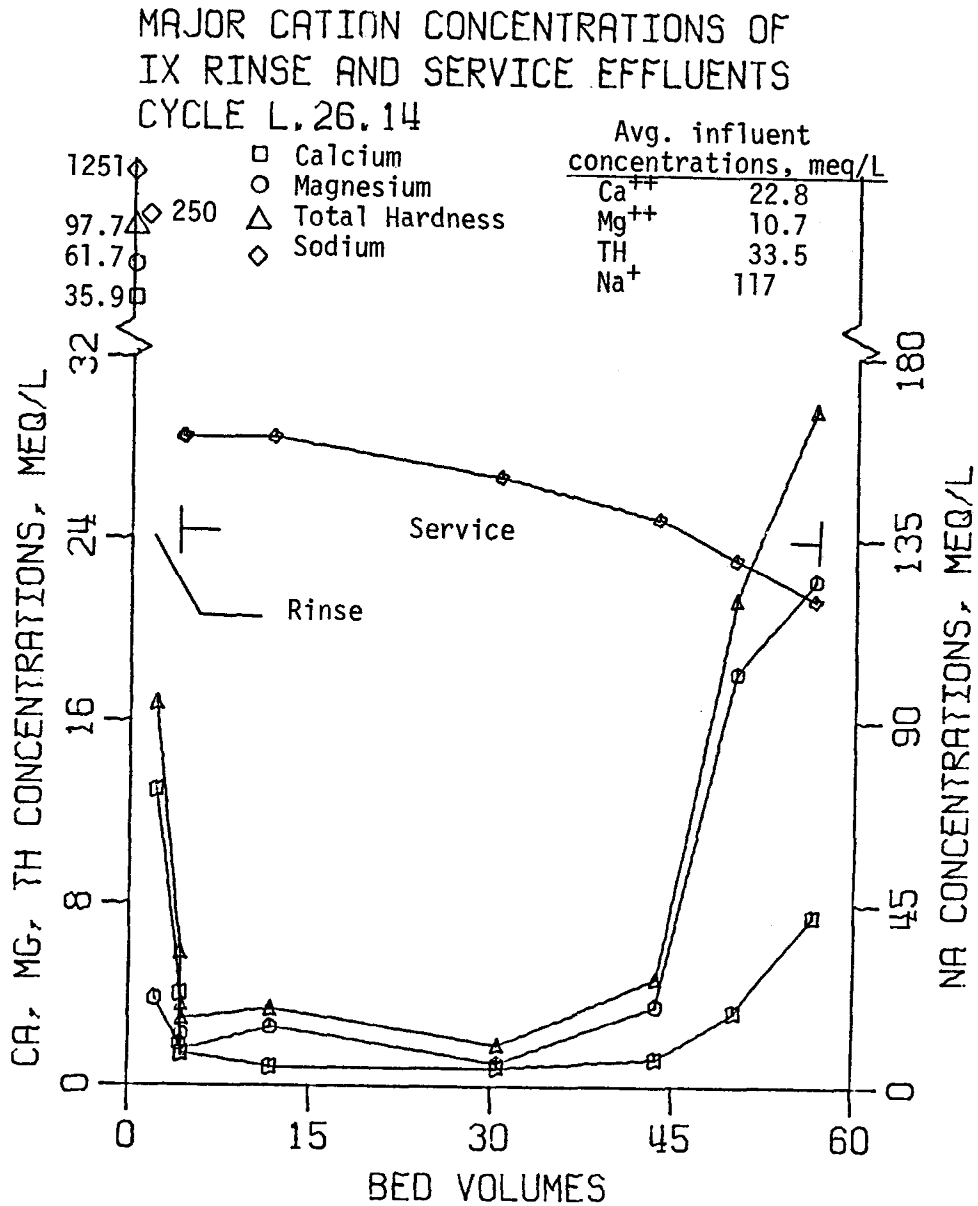
[a] Sample was diluted in the field (1/10). Values reflect undiluted concentrations.
[b] Questionable chemical analysis result.
[c] Concurrent upflow/downflow rinse effluent.
[d] Downflow rinse effluent.

SERVICE PERFORMANCE SUMMARY

CYCLE L.26.14

	AVERAGE CONCENTRATIONS, MEQ/L INFLUENT	EFFLUENT	DIFFERENCE	REMOVAL %	RESIN CAPACITY EQ/L	TIME-WEIGHTED RESIN CAPACITY μEQ/L · min
CA	22.79	1.64	21.14	93	1.103	~~.827~~ 3.97
MG	10.70	5.36	5.34	50	.278	~~.209~~ 1.00
TH	33.49	7.01	26.48	79	1.381	~~1.036~~ 4.97
NA	116.72	147.01	-30.30			





SODIUM (NA), CALCIUM (CA), AND MAGNESIUM (MG) CONCENTRATIONS ARE MEASURED BY ATOMIC ABSORPTION.
TOTAL HARDNESS (TH) IS CALCULATED BY SUMMING THE CALCIUM AND MAGNESIUM CONCENTRATIONS.

APPENDIX C

Computer Program for Calcium-Sulfate Supersaturation

```
10      !                    PROGRAM JONMAR
20      !       THIS PROGRAM CALCULATES THE AMOUNT OF CALCIUM
30      !       SULFATE PRECIPITATED FROM A SUPERSATURATED SOLUTION
40      !       BASED ON CaSO4 SOLUBILITY FOR A PARTICULAR TEMPERATURE.
50      !             JOHN KAAKINEN 9/83
60        OPTION BASE 1
70        PRINTER IS 7,1
80        DIM A$[40],B$[70],C$[70],D$[70],E$[70],T(21),A(20),R(20)
90        DISP "MARSHALL PROGRAM - CaSO4 SOLUBILITY"
100       WAIT 1000
110       Index=0
120       INPUT "SAMPLE DESCRIPTION ?",A$
130       INPUT "TEMPERATURE ?",T
140       I=1
150       T(I)=T
160       A(I)=T(I)+273.2
170       DISP "ENTER SAMPLE ANALYSIS (mg/L); ENTER 0 IF NOT DETECTED/USED"
180       WAIT 1000
190     !       INPUT CATION DATA
200       Ca=0
210       INPUT "CALCIUM (Ca) ?",Ca
220       Mcao=Ca/40080
230       Mg=0
240       INPUT "MAGNESIUM (Mg) ?",Mg
250       Na=0
260       INPUT "SODIUM (Na) ?",Na
270       K=0
280       INPUT "POTASSIUM (K) ?",K
290       Fe=0
300       INPUT "IRON (Fe) ?",Fe
310       Mn=0
320       INPUT "MANGANESE (Mn) ?",Mn
330       Sr=0
340       INPUT "STRONTIUM (Sr) ?",Sr
350       Ba=0
360       INPUT "BARIUM (Ba) ?",Ba
370     !       INPUT ANION DATA
380       Hca3=0
390       INPUT "BICARBONATE (HCO3) ?",Hco3
400       Co3=0
410       INPUT "CARBONATE (CO3) ?",Co3
420       So4=0
430       INPUT "SULFATE (SO4) ?",So4
440       Cl=0
450       INPUT "CHLORIDE (Cl) ?",Cl
460       Po4=0
470       INPUT "PHOSPHATE (PO4) ?",Po4
480     !       CONVERSION TO MILLIEQUIVALENTS
490       Eca=Ca/20.04
500       Emg=Mg/12.16
510       Ena=Na/22.99
520       Ek=K/39.1
530       Efe=Fe/27.92
540       Emn=Mn/27.47
550       Esr=Sr/43.81
560       Eba=Ba/68.67
570       Ehco3=Hco3/61.02
580       Eco3=Co3/30.0
590       Eso4=So4/48.02
600       Ecl=Cl/35.45
610       Epo4=Po4/31.65
620     !       CONVERSION TO MOLES
630       Mca=Ca/40080
640       Mmg=Mg/24312
650       Mna=Na/22990
660       Mk=K/39102
```

```
670         Mfe=Fe/55847
680         Mmn=Mn/54938
690         Msr=Sr/87620
700         Mba=Ba/137340
710         Mhco3=Hco3/61016
720         Mco3=Co3/60008
730         Mso4=So4/96060
740         Mcl=Cl/35453
750         Mpo4=Po4/94970
760    !        SUMMATION OF CATIONS AND ANIONS (e-MILLIEQUIVALENT, m-MOLES)
770         Scat=Ca+Mg+Na+K+Fe+Mn+Sr+Ba
780         San=Hco3+Co3+So4+Cl+Po4
790         Secat=Eca+Emg+Ena+Ek+Emn+Esr+Eba
800         Sean=Ehco3+Eco3+Eso4+Ecl+Epo4
810         Smcat=Mca+Mmg+Mna+Mk+Mfe+Mmn+Msr+Mba
820         Sman=Mhco3+Mco3+Mso4+Mcl+Mpo4
830    !        IONIC STRENGTH CALCULATION
840         U=9*Mpo4
850         V=4*(Mca+Mmg+Mfe+Mmn+Msr+Mba+Mco3+Mso4)
860         W=Mna+Mk+Mhco3+Mcl
870         Ionstr=.5*(U+V+W)
880    !        PRINT OUT CATION AND IONIC CONCENTRATIONS
890         PRINT LIN(1);"-------------------------------------------------------------
---------"
900         B$="     CATIONS                      mg/L            meq/L            mmoles/L
"
910         C$="      ANIONS                      mg/L            meq/L            mmoles/L
"
920         PRINT A$;LIN(2)
930         IMAGE "CALCIUM (Ca)"13X,DDDDD.DD,9X,DDD.DD,8X,DDD.DDD
940         IMAGE "MAGNESIUM (Mg)"11X,DDDDD.DD,9X,DDD.DD,8X,DDD.DDD
950         IMAGE "SODIUM (Na)"14X,DDDDD.DD,8X,DDDD.DD,7X,DDDD.DDD
960         IMAGE "POTASSIUM (PO4)"10X,DDDDD.DD,9X,DDD.DD,9X,DD.DDD
970         IMAGE "IRON (Fe)"17X,DDDD.DD,9X,DDD.DD,9X,DD.DDD
980         IMAGE "MANGANESE (Mn)"12X,DDDD.DD,9X,DDD.DD,9X,DD.DDD
990         IMAGE "STRONTIUM (Sr)"12X,DDDD.DD,9X,DDD.DD,9X,DD.DDD
1000        IMAGE "BARIUM (Ba)"15X,DDDD.DD,9X,DDD.DD,9X,DD.DDD
1010        IMAGE "BICARBONATE (HCO3)"7X,DDDDD.DD,9X,DDD.DD,8X,DDD.DDD
1020        IMAGE "CARBONATE (CO3)"10X,DDDDD.DD,9X,DDD.DD,9X,DD.DDD
1030        IMAGE "SULFATE (SO4)"12X,DDDDD.DD,9X,DDD.DD,8X,DDD.DDD
1040        IMAGE "CHLORIDE (Cl)"12X,DDDDD.DD,9X,DDD.DD,8X,DDD.DDD
1050        IMAGE "PHOSPHATE (PO4)"11X,DDDD.DD,9X,DDD.DD,9X,DD.DDD
1060        PRINT B$;LIN(1)
1070        PRINT USING 930;Ca,Eca,1000*Mca
1080        PRINT USING 940;Mg,Emg,Mmg*1000
1090        PRINT USING 950;Na,Ena,Mna*1000
1100        PRINT USING 960;K,Ek,Mk*1000
1110        PRINT USING 970;Fe,Efe,Mfe*1000
1120        PRINT USING 980;Mn,Emn,Mmn*1000
1130        PRINT USING 990;Sr,Esr,Msr*1000
1140        PRINT USING 1000;Ba,Eba,Mba*1000
1150        PRINT LIN(1);C$;LIN(1)
1160        PRINT USING 1010;Hco3,Ehco3,Mhco3*1000
1170        PRINT USING 1020;Co3,Eco3,Mco3*1000
1180        PRINT USING 1030;So4,Eso4,Mso4*1000
1190        PRINT USING 1040;Cl,Ecl,Mcl*1000
1200        PRINT USING 1050;Po4,Epo4,Mpo4*1000
1210        PRINT LIN(1)
1220        IMAGE "SUMMATION OF CATIONS = "2X,DDDD.D,2X"meq/L"
1230        IMAGE "SUMMATION OF ANIONS  = "2X,DDDD.D,2X"meq/L"
1240        IMAGE "RATIO CATIONS:ANIONS = "2X,DD.DD
1250        PRINT USING 1220;Secat
1260        PRINT USING 1230;Sean
1270        Ratio=Secat/Sean
1280        PRINT USING 1240;Ratio
1290        Tds=Scat+San
```

```
1300     IMAGE "TDS (SUMMATION)        = "2X,DDDDD.D,2X"mg/L"
1310     PRINT USING 1300;Tds
1320     IMAGE "IONIC STRENGTH         = "2X,D.DDDDD
1330     PRINT USING 1320;Ionstr
1340     IF Index=1 THEN GOTO 2050
1350     J=1
1360     C1=10^(390.9619-152.6246*LGT(A(J))-12545.6/A(J)+.0818493*A(J))
1370     C2=10^(-158.54+62.15*LGT(A(J))+4810.6/A(J)-.046298*A(J))
1380     IF (A(J)<=273) OR (A(J)>=550) THEN 2060
1390     IF A(J)>373 THEN 1420
1400     Dhslop=.00987*A(J)^.6939
1410     GOTO 1430
1420     Dhslop=.00008049*A(J)^1.506
1430     Para=1.6-.155*EXP(-.02054*T(J))
1440     Gyps1=.088*EXP(-.0605*T(J))
1450     Gyps2=.02*EXP(-.01336*T(J))
1460     C3=Mso4/Mca
1470     Slop1=C3*Mca^2
1480     C4=Ionstr*(.05838-.00326*Ionstr+.00012489*Ionstr^2)
1490     C5=Ionstr*(.997-.01883*Ionstr)
1500     C6=0
1510     C7=1
1520     FOR I=1 TO 100
1530           C8=Mca*C7
1540           C9=Mmg*C7
1550           Precov=Ionstr*C7-4*C6
1560           C10=C1*10^(8*Dhslop*SQR(Precov)/(1+Para*SQR(Precov))+Gyps1*Perco
v-Gyps2*Precov^2)
1570           C11=C2*10^(8*Dhslop*SQR(Precov)/(1+SQR(Precov)))
1580           C6=C9*C10/(C11*C8+C10)
1590           C12=SQR((C10+C6*C8)/Slop1)
1600           IF ABS(C12-C7)/C12-.001<=0 THEN 1630
1610           C7=C12
1620           NEXT I
1630        C13=C7*Ionstr
1640        C14=C13*(.05838-.00326*C13+.00012489*C13^2)/C4
1650        C15=C13*(.997-.01883*C13)/C5
1660        R=100-100/C15
1670        IF ABS(C12-1)-.005<0 THEN GOTO 1940
1680        Scr=(Mso4*C12-C6)/(Mca*C12)
1690        IF Scr<1 THEN GOTO 1740
1700        Caln=Mca*C12
1710        Mso4=Mso4-Mca+Caln
1720        Mca=Caln
1730        GOTO 1770
1740        Suln=Mso4*C12
1750        Mca=Mca-Mso4+Suln
1760        Mso4=Suln
1770        Ca=Mca*40080
1780        So4=Mso4*96060
1790        Eca=Ca/20.04
1800        Eso4=So4/48.02
1810    !      NEW SUMMATION OF CATIONS AND ANIONS (e-MILLIEQUIVALENT, m-MOLES)
1820      Scat=Ca+Mg+Na+K+Fe+Mn+Sr+Ba
1830      San=Hco3+Co3+So4+Cl+Po4
1840      Secat=Eca+Emg+Ena+Ek+Emn+Esr+Eba
1850      Sean=Ehco3+Eco3+Eso4+Ecl+Epo4
1860      Smcat=Mca+Mmg+Mna+Mk+Mfe+Mmn+Msr+Mba
1870     Sman=Mhco3+Mco3+Mso4+Mcl+Mpo4
1880    !   NEW IONIC STRENGTH CALCULATION
1890    U=9*Mpo4
1900    V=4*(Mca+Mmg+Mfe+Mmn+Msr+Mba+Mco3+Mso4)
1910    W=Mna+Mk+Mhco3+Mcl
1920    Ionstr=.5*(U+V+W)
1930     GOTO 1460
1940    !   CALCULATION COMPLETE.  PRINT OUT RESULT.
```

```
1950      Caprt=(Mcao-Mca)*1000
1960      PRINT LIN(1)
1970      IF Caprt<0 THEN GOTO 2110
1980      D$="NEW COMPOSITION AFTER CaSO4 PRECIPITATION"
1990      PRINT D$;LIN(1)
2000      PRINT USING 2010;T
2010      IMAGE "TEMPERATURE =  ",DD.DD,2X" oC"
2020      PRINT LIN(1)
2030      Index=1
2040      GOTO 1060
2050      PRINT LIN(1)
2060      IMAGE "CALCIUM SULFATE PRECIPITATED =   ",DDDDD.DDDD,2X"mmoles/L"
2070      IMAGE "                             =   ",DDDDD.DDDD,2X"g/L"
2080      IMAGE "CALCIUM SULFATE UNDERSATURATION =  ",DDDDD.DDDD,2X"mmoles/L"
2090      IF Caprt>=0 THEN PRINT USING 2060;Caprt
2100      IF Caprt>=0 THEN PRINT USING 2070;Caprt*.13614
2110      IF Caprt<0 THEN PRINT USING 2080;-Caprt
2120      GOTO 2140
2130       DISP "INCORRECT TEMPERATURE INPUT !"
2140       END
```

APPENDIX D

Calcium-Sulfate Supersaturation Calculation Results for Regeneration Effluent

L.02.12 R1/2E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2440.00	121.76	60.878
MAGNESIUM (Mg)	850.00	69.90	34.962
SODIUM (Na)	7521.00	327.14	327.142
POTASSIUM (PO4)	743.00	19.00	19.002
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	26.00	.59	.297
BARIUM (Ba)	0.00	0.00	0.000
ANIONS	**mg/L**	**meq/L**	**mmoles/L**
BICARBONATE (HCO3)	104.00	1.70	1.704
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	6290.00	130.99	65.480
CHLORIDE (Cl)	15500.00	437.24	437.199
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 538.4 meq/L
SUMMATION OF ANIONS = 569.9 meq/L
RATIO CATIONS:ANIONS = .94
TDS (SUMMATION) = 33474.0 mg/L
IONIC STRENGTH = .71576

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1401.98	69.96	34.980
MAGNESIUM (Mg)	850.00	69.90	34.962
SODIUM (Na)	7521.00	327.14	327.142
POTASSIUM (PO4)	743.00	19.00	19.002
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	26.00	.59	.297
BARIUM (Ba)	0.00	0.00	0.000
ANIONS	**mg/L**	**meq/L**	**mmoles/L**
BICARBONATE (HCO3)	104.00	1.70	1.704
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	3802.17	79.18	39.581
CHLORIDE (Cl)	15500.00	437.24	437.199
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 486.6 meq/L
SUMMATION OF ANIONS = 518.1 meq/L
RATIO CATIONS:ANIONS = .94
TDS (SUMMATION) = 29948.2 mg/L
IONIC STRENGTH = .61216

CALCIUM SULFATE PRECIPITATED = 25.8987 mmoles/L
= 3.5258 g/L

L.02.12 R1/2E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1340.00	66.87	33.433
MAGNESIUM (Mg)	537.00	44.16	22.088
SODIUM (Na)	9940.00	432.36	432.362
POTASSIUM (PO4)	743.00	19.00	19.002
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	26.00	.59	.297
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	104.00	1.70	1.704
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	6290.00	130.99	65.480
CHLORIDE (Cl)	15500.00	437.24	437.199
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 563.0 meq/L
SUMMATION OF ANIONS = 569.9 meq/L
RATIO CATIONS:ANIONS = .99
TDS (SUMMATION) = 34480.0 mg/L
IONIC STRENGTH = .68773

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	985.71	49.19	24.594
MAGNESIUM (Mg)	537.00	44.16	22.088
SODIUM (Na)	9940.00	432.36	432.362
POTASSIUM (PO4)	743.00	19.00	19.002
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	26.00	.59	.297
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	104.00	1.70	1.704
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	5440.88	113.30	56.640
CHLORIDE (Cl)	15500.00	437.24	437.199
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 545.3 meq/L
SUMMATION OF ANIONS = 552.2 meq/L
RATIO CATIONS:ANIONS = .99
TDS (SUMMATION) = 33276.6 mg/L
IONIC STRENGTH = .65237

CALCIUM SULFATE PRECIPITATED = 8.8395 mmoles/L
= 1.2034 g/L

L.03.35 R3E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	3180.00	158.68	79.341
MAGNESIUM (Mg)	875.00	71.96	35.990
SODIUM (Na)	8740.00	380.17	380.165
POTASSIUM (PO4)	782.00	20.00	19.999
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	32.00	.73	.365
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	189.00	3.10	3.098
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	9700.00	202.00	100.979
CHLORIDE (Cl)	16100.00	454.16	454.122
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 631.5 meq/L
SUMMATION OF ANIONS = 659.3 meq/L
RATIO CATIONS:ANIONS = .96
TDS (SUMMATION) = 39598.0 mg/L
IONIC STRENGTH = .86204

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1157.22	57.75	28.873
MAGNESIUM (Mg)	875.00	71.96	35.990
SODIUM (Na)	8740.00	380.17	380.165
POTASSIUM (PO4)	782.00	20.00	19.999
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	32.00	.73	.365
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	189.00	3.10	3.098
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	4851.98	101.04	50.510
CHLORIDE (Cl)	16100.00	454.16	454.122
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 530.6 meq/L
SUMMATION OF ANIONS = 558.3 meq/L
RATIO CATIONS:ANIONS = .95
TDS (SUMMATION) = 32727.2 mg/L
IONIC STRENGTH = .66017

CALCIUM SULFATE PRECIPITATED = 50.4686 mmoles/L
= 6.8708 g/L

L.03.35 R3E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2280.00	113.77	56.886
MAGNESIUM (Mg)	610.00	50.16	25.090
SODIUM (Na)	10600.00	461.07	461.070
POTASSIUM (PO4)	782.00	20.00	19.999
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	32.00	.73	.365
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	189.00	3.10	3.098
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	9700.00	202.00	100.979
CHLORIDE (Cl)	16100.00	454.16	454.122
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 645.7 meq/L
SUMMATION OF ANIONS = 659.3 meq/L
RATIO CATIONS:ANIONS = .98
TDS (SUMMATION) = 40293.0 mg/L
IONIC STRENGTH = .83579

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	884.06	44.11	22.057
MAGNESIUM (Mg)	610.00	50.16	25.090
SODIUM (Na)	10600.00	461.07	461.070
POTASSIUM (PO4)	782.00	20.00	19.999
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	32.00	.73	.365
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	189.00	3.10	3.098
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	6354.34	132.33	66.150
CHLORIDE (Cl)	16100.00	454.16	454.122
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 576.1 meq/L
SUMMATION OF ANIONS = 589.6 meq/L
RATIO CATIONS:ANIONS = .98
TDS (SUMMATION) = 35551.4 mg/L
IONIC STRENGTH = .69647

CALCIUM SULFATE PRECIPITATED = 34.8288 mmoles/L
= 4.7416 g/L

L.05.54 R3E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	6280.00	313.37	156.687
MAGNESIUM (Mg)	1555.00	127.88	63.960
SODIUM (Na)	18699.00	813.35	813.354
POTASSIUM (PO4)	1080.00	27.62	27.620
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	50.00	1.14	.571
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	91.00	1.49	1.491
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	13200.00	274.89	137.414
CHLORIDE (Cl)	21300.00	600.85	600.795
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1283.4 meq/L
SUMMATION OF ANIONS = 877.2 meq/L
RATIO CATIONS:ANIONS = 1.46
TDS (SUMMATION) = 62255.6 mg/L
IONIC STRENGTH = 1.43891

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2252.33	112.39	56.196
MAGNESIUM (Mg)	1555.00	127.88	63.960
SODIUM (Na)	18699.00	813.35	813.354
POTASSIUM (PO4)	1080.00	27.62	27.620
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	50.00	1.14	.571
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	91.00	1.49	1.491
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	3546.87	73.86	36.923
CHLORIDE (Cl)	21300.00	600.85	600.795
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1082.4 meq/L
SUMMATION OF ANIONS = 676.2 meq/L
RATIO CATIONS:ANIONS = 1.60
TDS (SUMMATION) = 48574.8 mg/L
IONIC STRENGTH = 1.03695

CALCIUM SULFATE PRECIPITATED = 100.4907 mmoles/L
= 13.6808 g/L

L.05.54 R3E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	3900.00	194.61	97.305
MAGNESIUM (Mg)	1190.00	97.86	48.947
SODIUM (Na)	12900.00	561.11	561.114
POTASSIUM (PO4)	1080.00	27.62	27.620
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	50.00	1.14	.571
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	91.00	1.49	1.491
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	13200.00	274.89	137.414
CHLORIDE (Cl)	21300.00	600.85	600.795
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 882.3 meq/L
SUMMATION OF ANIONS = 877.2 meq/L
RATIO CATIONS:ANIONS = 1.01
TDS (SUMMATION) = 53711.0 mg/L
IONIC STRENGTH = 1.16398

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1077.11	53.75	26.874
MAGNESIUM (Mg)	1190.00	97.86	48.947
SODIUM (Na)	12900.00	561.11	561.114
POTASSIUM (PO4)	1080.00	27.62	27.620
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	50.00	1.14	.571
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	91.00	1.49	1.491
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	6434.37	133.99	66.983
CHLORIDE (Cl)	21300.00	600.85	600.795
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 741.5 meq/L
SUMMATION OF ANIONS = 736.3 meq/L
RATIO CATIONS:ANIONS = 1.01
TDS (SUMMATION) = 44122.5 mg/L
IONIC STRENGTH = .88226

CALCIUM SULFATE PRECIPITATED = 70.4313 mmoles/L
= 9.5885 g/L

L.10.14 R2E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	4500.00	224.55	112.275
MAGNESIUM (Mg)	1774.00	145.89	72.968
SODIUM (Na)	15502.00	674.29	674.293
POTASSIUM (PO4)	1370.00	35.04	35.037
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	43.00	.98	.491
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	122.00	2.00	1.999
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	11900.00	247.81	123.881
CHLORIDE (Cl)	32000.00	902.68	902.603
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1080.8 meq/L
SUMMATION OF ANIONS = 1152.5 meq/L
RATIO CATIONS:ANIONS = .94
TDS (SUMMATION) = 67211.6 mg/L
IONIC STRENGTH = 1.42622

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1671.91	83.43	41.714
MAGNESIUM (Mg)	1774.00	145.89	72.968
SODIUM (Na)	15502.00	674.29	674.293
POTASSIUM (PO4)	1370.00	35.04	35.037
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	43.00	.98	.491
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	122.00	2.00	1.999
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	5121.90	106.66	53.320
CHLORIDE (Cl)	32000.00	902.68	902.603
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 939.6 meq/L
SUMMATION OF ANIONS = 1011.3 meq/L
RATIO CATIONS:ANIONS = .93
TDS (SUMMATION) = 57605.4 mg/L
IONIC STRENGTH = 1.14397

CALCIUM SULFATE PRECIPITATED = 70.5611 mmoles/L
= 9.6062 g/L

L.10.14 R2E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2150.00	107.29	53.643
MAGNESIUM (Mg)	1340.00	110.20	55.117
SODIUM (Na)	20500.00	891.69	891.692
POTASSIUM (PO4)	1370.00	35.04	35.037
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	43.00	.98	.491
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	122.00	2.00	1.999
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	11900.00	247.81	123.881
CHLORIDE (Cl)	32000.00	902.68	902.603
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1145.2 meq/L
SUMMATION OF ANIONS = 1152.5 meq/L
RATIO CATIONS:ANIONS = .99
TDS (SUMMATION) = 69425.6 mg/L
IONIC STRENGTH = 1.38195

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	958.21	47.81	23.907
MAGNESIUM (Mg)	1340.00	110.20	55.117
SODIUM (Na)	20500.00	891.69	891.692
POTASSIUM (PO4)	1370.00	35.04	35.037
IRON (Fe)	.60	.02	.011
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	43.00	.98	.491
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	122.00	2.00	1.999
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	9043.63	188.33	94.146
CHLORIDE (Cl)	32000.00	902.68	902.603
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1085.7 meq/L
SUMMATION OF ANIONS = 1093.0 meq/L
RATIO CATIONS:ANIONS = .99
TDS (SUMMATION) = 65377.4 mg/L
IONIC STRENGTH = 1.26301

CALCIUM SULFATE PRECIPITATED = 29.7353 mmoles/L
= 4.0482 g/L

L.22.15 R2E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	4640.00	231.54	115.768
MAGNESIUM (Mg)	1737.00	142.85	71.446
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1550.00	39.64	39.640
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.00	1.07	.536
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	118.00	1.93	1.934
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	12600.00	262.39	131.168
CHLORIDE (Cl)	32800.00	925.25	925.169
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1415.5 meq/L
SUMMATION OF ANIONS = 1189.6 meq/L
RATIO CATIONS:ANIONS = 1.19
TDS (SUMMATION) = 76492.0 mg/L
IONIC STRENGTH = 1.62143

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1673.04	83.49	41.743
MAGNESIUM (Mg)	1737.00	142.85	71.446
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1550.00	39.64	39.640
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.00	1.07	.536
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	118.00	1.93	1.934
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	5489.07	114.31	57.142
CHLORIDE (Cl)	32800.00	925.25	925.169
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1267.5 meq/L
SUMMATION OF ANIONS = 1041.5 meq/L
RATIO CATIONS:ANIONS = 1.22
TDS (SUMMATION) = 66414.1 mg/L
IONIC STRENGTH = 1.32532

CALCIUM SULFATE PRECIPITATED = 74.0259 mmoles/L
= 10.0779 g/L

L.22.15 R2E ävg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2620.00	130.74	65.369
MAGNESIUM (Mg)	1470.00	120.89	60.464
SODIUM (Na)	21700.00	943.89	943.889
POTASSIUM (PO4)	1550.00	39.64	39.640
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.00	1.07	.536
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	118.00	1.93	1.934
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	12600.00	262.39	131.168
CHLORIDE (Cl)	32800.00	925.25	925.169
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1236.2 meq/L
SUMMATION OF ANIONS = 1189.6 meq/L
RATIO CATIONS:ANIONS = 1.04
TDS (SUMMATION) = 72905.0 mg/L
IONIC STRENGTH = 1.47039

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1014.52	50.62	25.312
MAGNESIUM (Mg)	1470.00	120.89	60.464
SODIUM (Na)	21700.00	943.89	943.889
POTASSIUM (PO4)	1550.00	39.64	39.640
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.00	1.07	.536
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	118.00	1.93	1.934
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	8752.13	182.26	91.111
CHLORIDE (Cl)	32800.00	925.25	925.169
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1156.1 meq/L
SUMMATION OF ANIONS = 1109.4 meq/L
RATIO CATIONS:ANIONS = 1.04
TDS (SUMMATION) = 67451.6 mg/L
IONIC STRENGTH = 1.31016

CALCIUM SULFATE PRECIPITATED = 40.0569 mmoles/L
= 5.4534 g/L

L.23.19 R3E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	8180.00	408.18	204.092
MAGNESIUM (Mg)	2199.00	180.84	90.449
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1660.00	42.46	42.453
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.70	1.09	.544
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	7.93	.13	.130
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	18800.00	391.50	195.711
CHLORIDE (Cl)	29400.00	829.34	829.267
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1633.0 meq/L
SUMMATION OF ANIONS = 1221.0 meq/L
RATIO CATIONS:ANIONS = 1.34
TDS (SUMMATION) = 83294.6 mg/L
IONIC STRENGTH = 1.91774

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2150.77	107.32	53.662
MAGNESIUM (Mg)	2199.00	180.84	90.449
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1660.00	42.46	42.453
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.70	1.09	.544
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	7.93	.13	.130
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	4349.70	90.58	45.281
CHLORIDE (Cl)	29400.00	829.34	829.267
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1332.1 meq/L
SUMMATION OF ANIONS = 920.0 meq/L
RATIO CATIONS:ANIONS = 1.45
TDS (SUMMATION) = 62815.1 mg/L
IONIC STRENGTH = 1.31602

CALCIUM SULFATE PRECIPITATED = 150.4299 mmoles/L
= 20.4795 g/L

L.23.19 R3E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	4130.00	206.09	103.044
MAGNESIUM (Mg)	1290.00	106.09	53.060
SODIUM (Na)	20600.00	896.04	896.042
POTASSIUM (PO4)	1660.00	42.46	42.453
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.70	1.09	.544
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	7.93	.13	.130
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	18800.00	391.50	195.711
CHLORIDE (Cl)	29400.00	829.34	829.267
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1251.8 meq/L
SUMMATION OF ANIONS = 1221.0 meq/L
RATIO CATIONS:ANIONS = 1.03
TDS (SUMMATION) = 75935.6 mg/L
IONIC STRENGTH = 1.58866

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	795.85	39.71	19.857
MAGNESIUM (Mg)	1290.00	106.09	53.060
SODIUM (Na)	20600.00	896.04	896.042
POTASSIUM (PO4)	1660.00	42.46	42.453
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	47.70	1.09	.544
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	7.93	.13	.130
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	10809.02	225.09	112.524
CHLORIDE (Cl)	29400.00	829.34	829.267
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1085.4 meq/L
SUMMATION OF ANIONS = 1054.6 meq/L
RATIO CATIONS:ANIONS = 1.03
TDS (SUMMATION) = 64610.5 mg/L
IONIC STRENGTH = 1.25592

CALCIUM SULFATE PRECIPITATED = 83.1873 mmoles/L
= 11.3251 g/L

L.24.11 R3E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	7740.00	386.23	193.114
MAGNESIUM (Mg)	1616.00	132.89	66.469
SODIUM (Na)	21413.00	931.40	931.405
POTASSIUM (PO4)	1470.00	37.60	37.594
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	41.00	.94	.468
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	18100.00	376.93	188.424
CHLORIDE (Cl)	26700.00	753.17	753.110
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1489.1 meq/L
SUMMATION OF ANIONS = 1131.2 meq/L
RATIO CATIONS:ANIONS = 1.32
TDS (SUMMATION) = 77147.1 mg/L
IONIC STRENGTH = 1.75855

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1992.82	99.44	49.721
MAGNESIUM (Mg)	1616.00	132.89	66.469
SODIUM (Na)	21413.00	931.40	931.405
POTASSIUM (PO4)	1470.00	37.60	37.594
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	41.00	.94	.468
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	4325.71	90.08	45.031
CHLORIDE (Cl)	26700.00	753.17	753.110
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1202.3 meq/L
SUMMATION OF ANIONS = 844.4 meq/L
RATIO CATIONS:ANIONS = 1.42
TDS (SUMMATION) = 57625.6 mg/L
IONIC STRENGTH = 1.18498

CALCIUM SULFATE PRECIPITATED = 143.3926 mmoles/L
= 19.5215 g/L

L.24.11 R3E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	3680.00	183.63	91.816
MAGNESIUM (Mg)	1270.00	104.44	52.238
SODIUM (Na)	19800.00	861.24	861.244
POTASSIUM (PO4)	1470.00	37.60	37.594
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	41.00	.94	.468
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	18100.00	376.93	188.424
CHLORIDE (Cl)	26700.00	753.17	753.110
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1187.8 meq/L
SUMMATION OF ANIONS = 1131.2 meq/L
RATIO CATIONS:ANIONS = 1.05
TDS (SUMMATION) = 71128.1 mg/L
IONIC STRENGTH = 1.49242

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	751.61	37.51	18.753
MAGNESIUM (Mg)	1270.00	104.44	52.238
SODIUM (Na)	19800.00	861.24	861.244
POTASSIUM (PO4)	1470.00	37.60	37.594
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	41.00	.94	.468
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	11081.51	230.77	115.360
CHLORIDE (Cl)	26700.00	753.17	753.110
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1041.7 meq/L
SUMMATION OF ANIONS = 985.0 meq/L
RATIO CATIONS:ANIONS = 1.06
TDS (SUMMATION) = 61181.2 mg/L
IONIC STRENGTH = 1.20016

CALCIUM SULFATE PRECIPITATED = 73.0636 mmoles/L
= 9.9469 g/L

L.26.14 R2E peak

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	4600.00	229.54	114.770
MAGNESIUM (Mg)	1895.00	155.84	77.945
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1740.00	44.50	44.499
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	3.90	.09	.045
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	15600.00	324.86	162.399
CHLORIDE (Cl)	32700.00	922.43	922.348
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1430.4 meq/L
SUMMATION OF ANIONS = 1248.4 meq/L
RATIO CATIONS:ANIONS = 1.15
TDS (SUMMATION) = 79606.0 mg/L
IONIC STRENGTH = 1.69451

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	1233.23	61.54	30.769
MAGNESIUM (Mg)	1895.00	155.84	77.945
SODIUM (Na)	23000.00	1000.43	1000.435
POTASSIUM (PO4)	1740.00	44.50	44.499
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	3.90	.09	.045
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	7530.84	156.83	78.397
CHLORIDE (Cl)	32700.00	922.43	922.348
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1262.4 meq/L
SUMMATION OF ANIONS = 1080.4 meq/L
RATIO CATIONS:ANIONS = 1.17
TDS (SUMMATION) = 68170.1 mg/L
IONIC STRENGTH = 1.35850

CALCIUM SULFATE PRECIPITATED = 84.0012 mmoles/L
= 11.4359 g/L

L.26.14 R2E avg

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	2640.00	131.74	65.868
MAGNESIUM (Mg)	1350.00	111.02	55.528
SODIUM (Na)	22100.00	961.29	961.288
POTASSIUM (PO4)	1740.00	44.50	44.499
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	3.90	.09	.045
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	15600.00	324.86	162.399
CHLORIDE (Cl)	32700.00	922.43	922.348
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1248.6 meq/L
SUMMATION OF ANIONS = 1248.4 meq/L
RATIO CATIONS:ANIONS = 1.00
TDS (SUMMATION) = 76201.0 mg/L
IONIC STRENGTH = 1.53230

NEW COMPOSITION AFTER CaSO4 PRECIPITATION

TEMPERATURE = 25.00 oC

CATIONS	mg/L	meq/L	mmoles/L
CALCIUM (Ca)	808.95	40.37	20.184
MAGNESIUM (Mg)	1350.00	111.02	55.528
SODIUM (Na)	22100.00	961.29	961.288
POTASSIUM (PO4)	1740.00	44.50	44.499
IRON (Fe)	0.00	0.00	0.000
MANGANESE (Mn)	0.00	0.00	0.000
STRONTIUM (Sr)	3.90	.09	.045
BARIUM (Ba)	0.00	0.00	0.000

ANIONS	mg/L	meq/L	mmoles/L
BICARBONATE (HCO3)	67.10	1.10	1.100
CARBONATE (CO3)	0.00	0.00	0.000
SULFATE (SO4)	11211.52	233.48	116.714
CHLORIDE (Cl)	32700.00	922.43	922.348
PHOSPHATE (PO4)	0.00	0.00	0.000

SUMMATION OF CATIONS = 1157.3 meq/L
SUMMATION OF ANIONS = 1157.0 meq/L
RATIO CATIONS:ANIONS = 1.00
TDS (SUMMATION) = 69981.5 mg/L
IONIC STRENGTH = 1.34956

CALCIUM SULFATE PRECIPITATED = 45.6848 mmoles/L
= 6.2195 g/L

APPENDIX E

Sample IX Data Sheets

COMPUTATION SHEET

★ U.S. Government Printing Office: 1977-779-651

BY	DATE	PROJECT	SHEET ____ OF ____
CHKD BY	DATE	FEATURE	
DETAILS			

Cycle # 1.01.01 A — Exhaustion — File 1

General Description:

Composition: F-1

Desired	Actual
Temp.: 15°C	Temp.: 17°C
Flow Rate: 11ml/s	Flow Rate: 11.5 ml/s

Concentrations - Desired/Actual:

Solution F-1

DESIRED		ACTUAL	
22meq/L Ca	100meq/L Na	21.8 meq/L Ca	89.6 meq/L Na
11 meq/L Mg		11.8 meq/L Mg	

Comments/Results:

This cycle only involved the exhaustion of the column. It was intended to be a trail cycle to determine if there were any problems in the system. The cycle ran smoothly and no problems were experienced with the system.

Cycle # ________

General Description:

Concentrations - Desired/Actual:

Comments/Results:

Record of Samples Taken

Cycle number 1.01.01A Date 7/11/80

Sample number	time taken	location	comments	Bed Volumes
1	10:17	Effluent-Service		0.3
2	10:22	" "		6.9
3	10:27	" "		13.8
4	10:37	" "		27.6
5	10:47	" "		41.4
6	10:57	" "		55.2
7	11:02	TANK-Service		0
8	11:07	Effluent-Service		69.0
9	11:17	" "		82.8
10	11:27	" "		96.6
11	11:37	" "		110.4
12	11:47	" "		124.2
13	12:17	" "		165.6
14	12:27	" "		179.4
15	12:37	" "		193.2
16	12:47	" "		207
17	12:57	" "		220.8
18	13:08	" "		234.6
19	13:17	" "		248.4
20	13:27	" "		262.2
21	13:37	" "		276.0
22	13:47	" "	140	289.8

Cycle # ______

Cycle number 1.01.01 A Date of Cycle 7-11-80 Date of Analysis ______

Sample number	initials	initial Vol. EDTA	final Vol. EDTA	Normality of EDTA	meq/l Ca	Total Hardness	meq/l Mg	%T Na	meq/l Na	Conductivity	BED VOLUMES
1	KM	4.94	6.75	.0196	0	3.5	3.5	1.9	0.5		0.3
2	KM	11.00	12.53		0	3.0	3.0	1/25 75.0	126.3		6.9
7	K.M. Ca TH	0.00 0.00	11.1 17.15	0.0196 0.0196	21.8	33.6	11.8		89.6		0
6	K.M.	15.50 0	18.90 8.94		5.7	17.5	11.8	1/25 70.1	109.5		55.2
3		0.00 2.50	0.14 3.84		0.27	1.50	1.23	1/25 75.8	130		13.8
8		10.0 16.98	16.13 31.08		120	27.6	15.6	1/25 67.4	97		69.0
5		0.00 12.2	0.59 16.5		1.12	8.6	7.48	1/25 72.8	117		41.4
10		3.00 0.00	12.25 16.8		18.1	33.6	15.5	1/25 66.5	93.5		96.6

Comments:

Cycle number 1.01.01 A Date of Cycle 7/11/80 Date of Analysis ______

Cycle # ______

Sample number	initials	initial Vol. EDTA	Final Vol. EDTA	Normality of EDTA	meq/l Ca	Total Hardness	meq/l Mg	%T Na	meq/l Na	Conductivity	BED VOLUMES
4	L.L. TH Ca	3.9 6.9	5.8 7.1	.0196	.4	3.8	34	1-200 26.3	120		27.6
9	L.L. TH Ca	7.1 0	22.5 8.4		16.8	30.8	14.00	1/25 67.2	96.3		82.8
15	TH Ca	8.4, 0 1.2	25, 0.7 12.9		23.4	34.6	11.2	66.2	93		193.2
20	Ca TH	16.8, 0 3.0	25, 3.0 26.8		22.4	35.6	13.2	66.5	93.8		262.2
12	Ca TH	0.6 11.6, 0	11.6 25.0, 4.2		22.0	35.2	13.2	1-200 21.5	80		124.2
TANK 2		4.2 15.6, 0	15.6 25.0, 8.3		22.8	35.4	12.6				

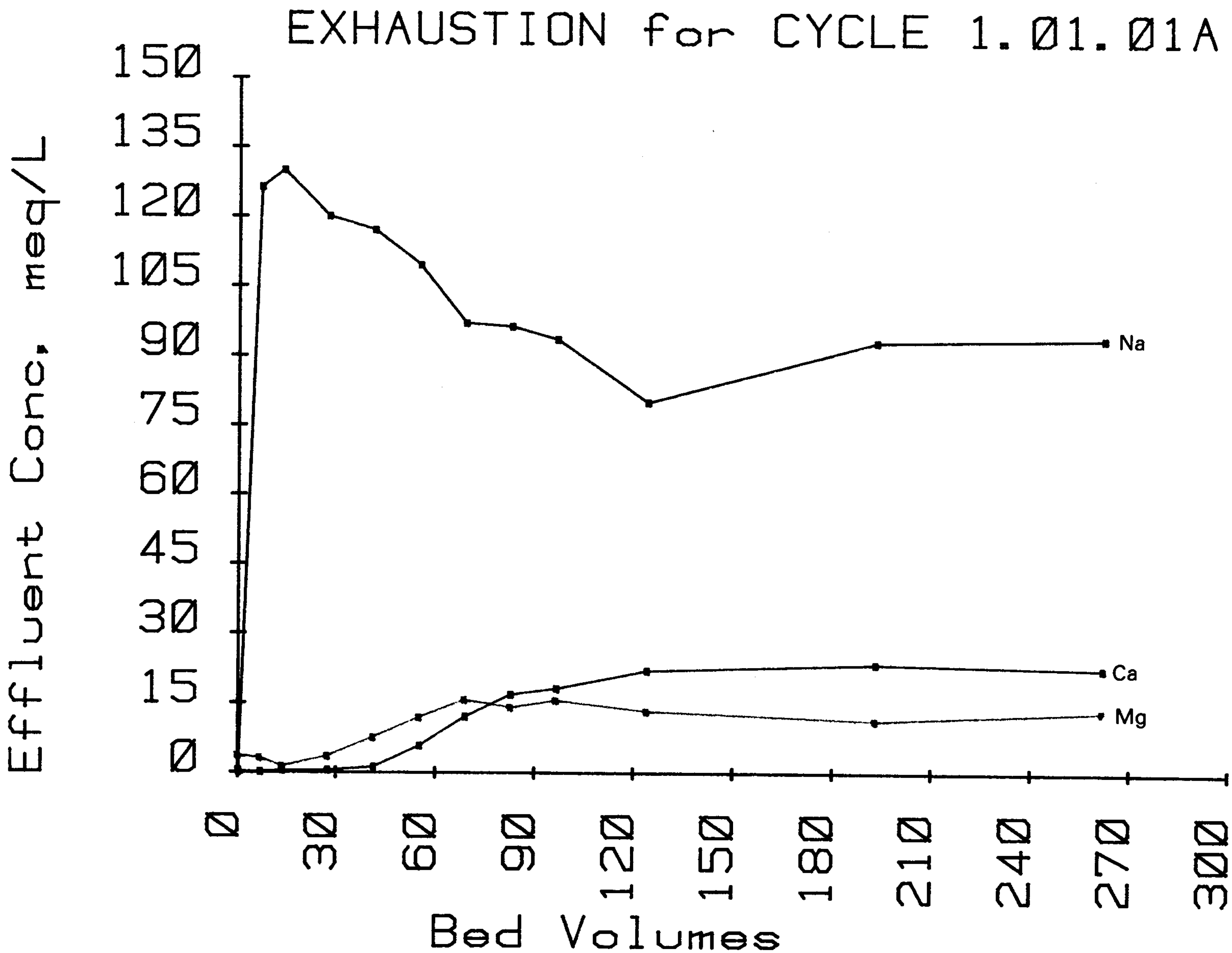
Comments:

APPENDIX F

Laboratory IX Data

EXHAUSTION for CYCLE 1.01.01A Date: 7/11/80

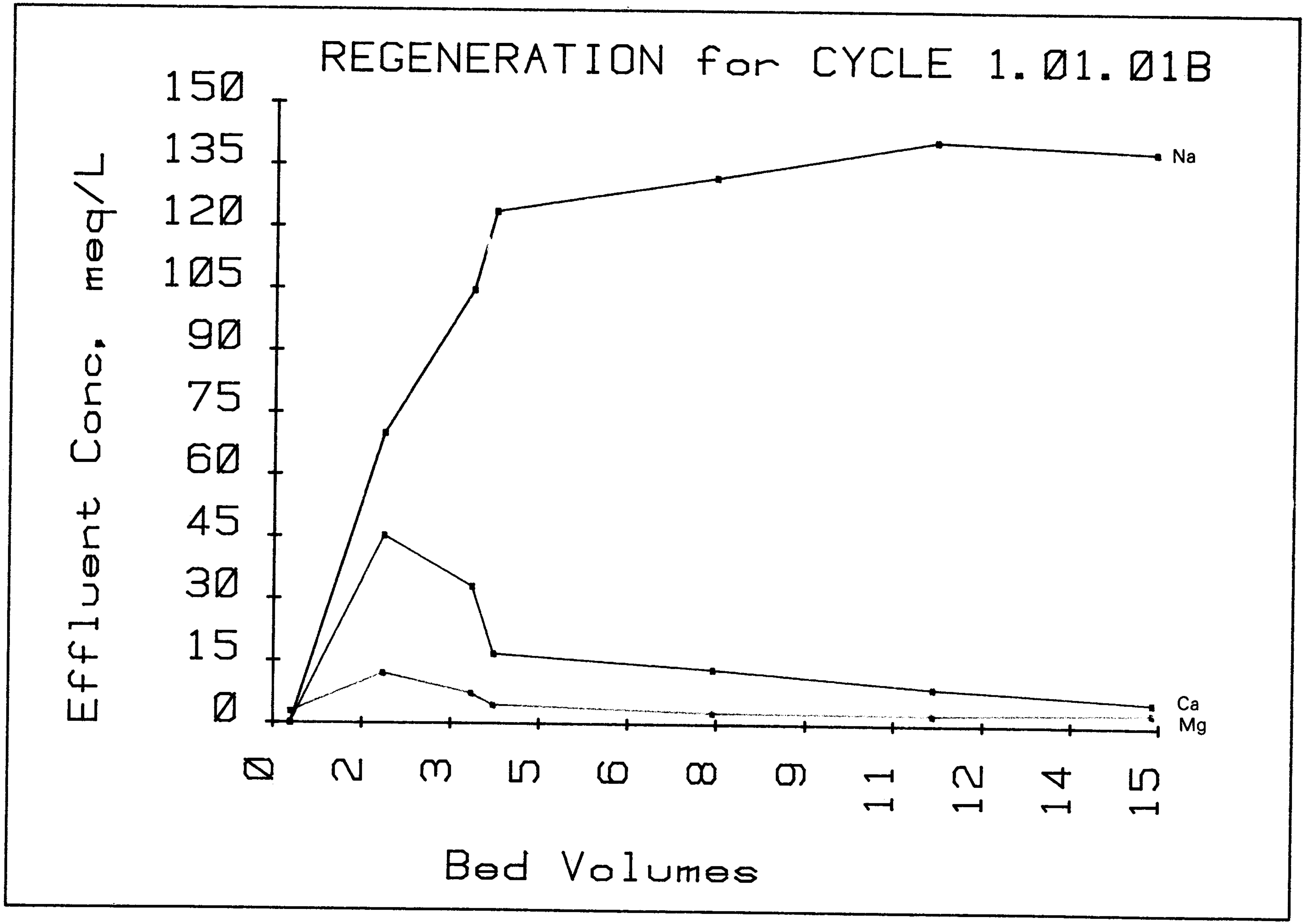
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.00	3.50	0.50
2	6.90	0.00	3.00	126.30
3	13.80	0.27	1.23	130.00
4	27.60	0.40	3.40	120.00
5	41.40	1.12	7.48	117.00
6	55.20	5.70	11.80	109.50
7	69.00	12.00	15.60	97.00
8	82.80	16.80	14.00	96.30
9	96.60	18.10	15.50	93.50
10	124.20	22.00	13.20	80.00
11	193.20	23.40	11.20	93.00
12	262.20	22.40	13.20	93.80
Influent		21.80	11.80	89.60
Conc Ratios (C/C0):				
1	0.30	0.00	0.30	0.01
2	6.90	0.00	0.25	1.41
3	13.80	0.01	0.10	1.45
4	27.60	0.02	0.29	1.34
5	41.40	0.05	0.63	1.31
6	55.20	0.26	1.00	1.22
7	69.00	0.55	1.32	1.08
8	82.80	0.77	1.19	1.07
9	96.60	0.83	1.31	1.04
10	124.20	1.01	1.12	0.89
11	193.20	1.07	0.95	1.04
12	262.20	1.03	1.12	1.05
Average effluent		16.51	11.27	95.84
Total resin capacity		1.38	0.14	-1.64
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	55.86	6.00	11.98	108.90
Average effluent		1.20	5.11	113.35
Resin capacity		1.14	0.37	-1.32
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	69.00	12.00	15.60	97.00
Average effluent		2.70	6.77	111.36
Resin capacity		1.31	0.35	-1.50


EXHAUSTION for CYCLE 1.01.01A
Effluent Conc. meq/L
150
135
120
105
90
75
60
45
30
15
0
Na
Ca
Mg
0
30
60
90
120
150
180
210
240
270
300
Bed Volumes

File 2

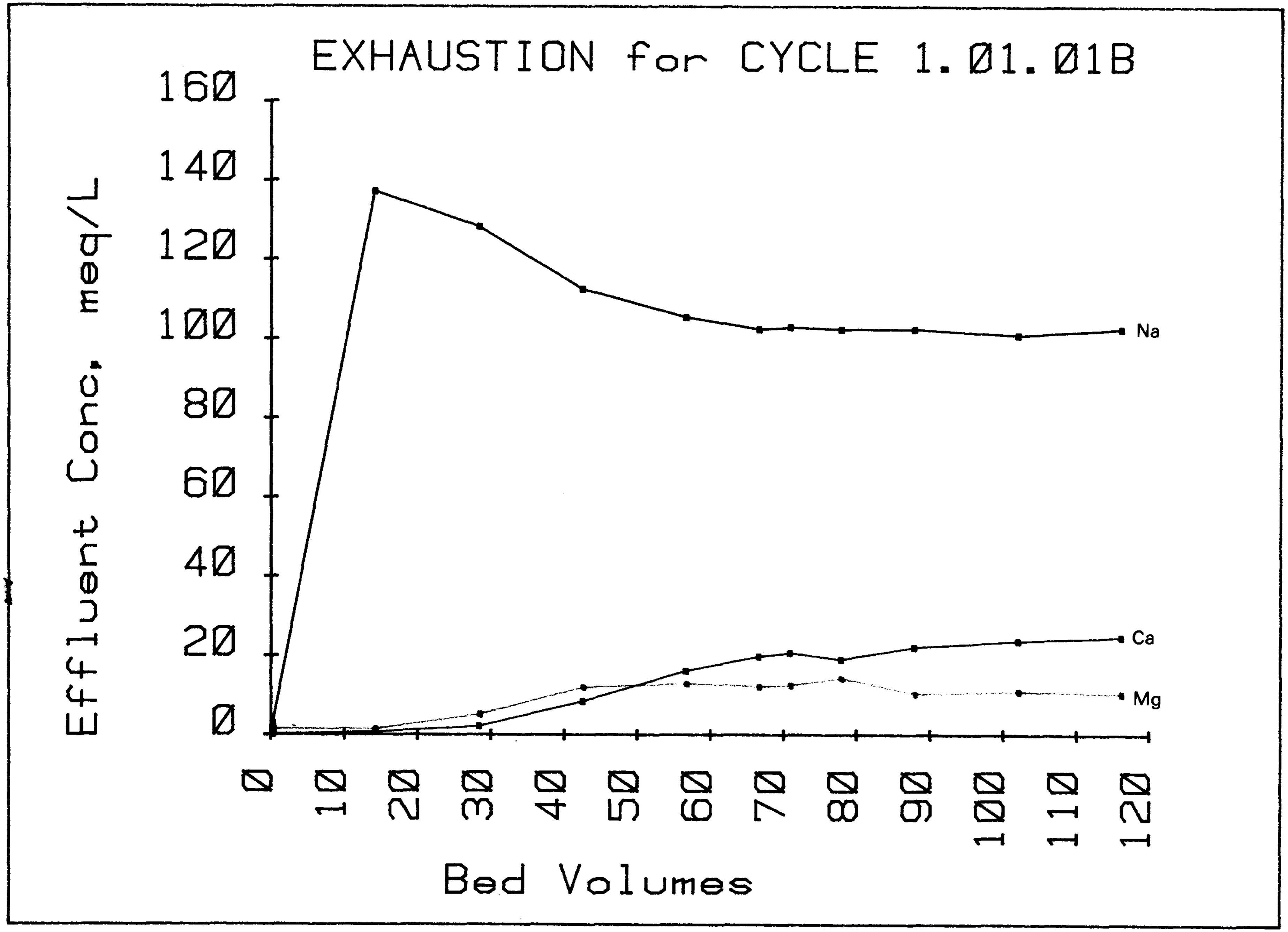
REGENERATION for CYCLE 1.01.01B Date: 7/15/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.10	2.60	0.90
2	1.86	45.10	11.90	700.00
3	3.35	32.90	7.10	1046.00
4	3.72	16.70	4.30	1236.00
5	7.44	13.10	2.60	1320.00
6	11.16	8.80	2.40	1410.00
7	14.88	5.70	3.10	1386.00
Influent		31.00	36.00	1420.00
Average effluent		15.48	4.11	1186.71
Total resin capacity		0.23	0.46	3.40


REGENERATION for CYCLE 1.Ø1.Ø1B
Effluent Conc. meq/L
150
135
120
105
90
75
60
45
30
15
Ø
Na
Ca
Mg
Ø
2
3
5
6
8
9
11
12
14
15
Bed Volumes

EXHAUSTION for CYCLE 1.01.01B Date: 7/15/80

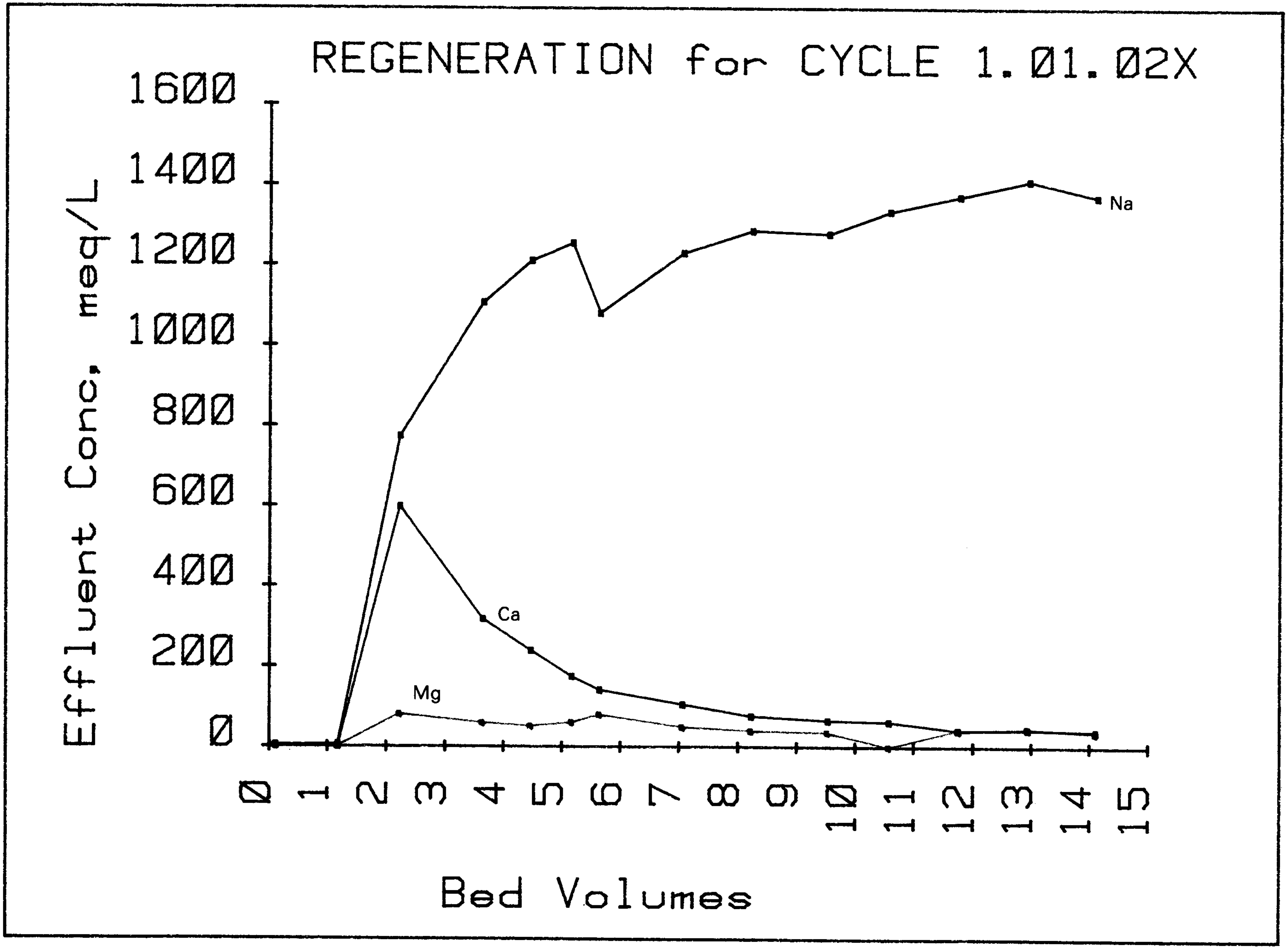
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.20	1.56	3.02
2	14.16	0.78	1.57	137.30
3	28.32	2.20	5.25	128.30
4	42.48	8.50	12.10	112.50
5	56.64	16.20	13.00	105.50
6	66.55	19.80	12.30	102.50
7	70.80	20.70	12.60	103.00
8	77.80	19.10	14.40	102.50
9	87.79	22.20	10.50	102.50
10	101.95	23.80	11.10	101.00
11	116.11	24.80	10.50	102.50
Influent		24.30	22.70	108.50
Conc Ratios (C/C0):				
1	0.30	0.01	0.07	0.03
2	14.16	0.03	0.07	1.27
3	28.32	0.09	0.23	1.18
4	42.48	0.35	0.53	1.04
5	56.64	0.67	0.57	0.97
6	66.55	0.81	0.54	0.94
7	70.80	0.85	0.56	0.95
8	77.80	0.79	0.63	0.94
9	87.79	0.91	0.46	0.94
10	101.95	0.98	0.49	0.93
11	116.11	1.02	0.46	0.94
Average effluent		13.46	9.27	105.29
Total resin capacity		1.26	1.56	0.37
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	36.86	6.00	9.38	118.77
Average effluent		1.72	3.62	106.89
Resin capacity		0.83	0.70	0.06
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	48.92	12.00	12.51	109.32
Average effluent		3.49	5.60	108.43
Resin capacity		1.01	0.83	0.00


EXHAUSTION for CYCLE 1.01.01B
Effluent Conc, meq/L
160
140
120
100
80
60
40
20
0
Na
Ca
Mg
0
10
20
30
40
50
60
70
80
90
100
110
120
Bed Volumes

File 4

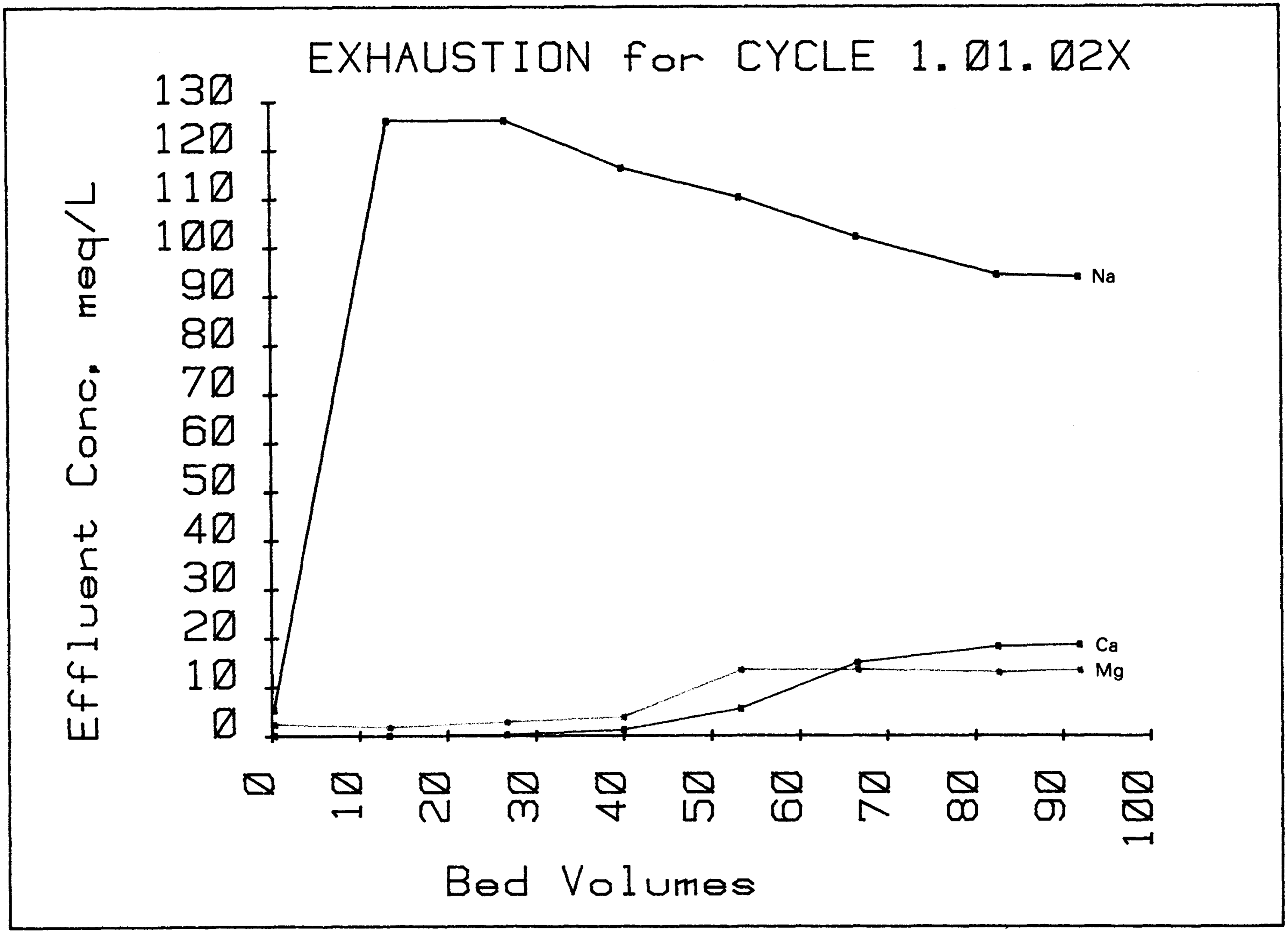
REGENERATION for CYCLE 1.01.02X Date: 7/16/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.12	0.59	1.80	4.00
2	1.18	0.20	0.58	6.00
3	2.23	597.80	80.20	774.00
4	3.65	317.50	58.50	1106.00
5	4.47	239.10	50.90	1210.00
6	5.17	175.00	60.20	1254.00
7	5.64	141.70	79.80	1080.00
8	7.06	105.80	49.00	1230.00
9	8.23	76.40	39.60	1286.00
10	9.53	66.00	36.00	1278.00
11	10.58	62.70	31.30	1334.00
12	11.76	42.00	42.00	1372.00
13	12.94	44.00	46.00	1410.00
14	14.11	40.00	36.00	1370.00
Influent		36.70	26.20	1400.00
Average effluent		144.10	45.01	1081.07
Total resin capacity		-1.50	-0.26	4.46


REGENERATION for CYCLE 1.01.02X
Effluent Conc, meq/L
1600
1400
1200
1000
800
600
400
200
0
Na
Ca
Mg
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Bed Volumes

EXHAUSTION for CYCLE 1.01.02X Date: 7/16/80

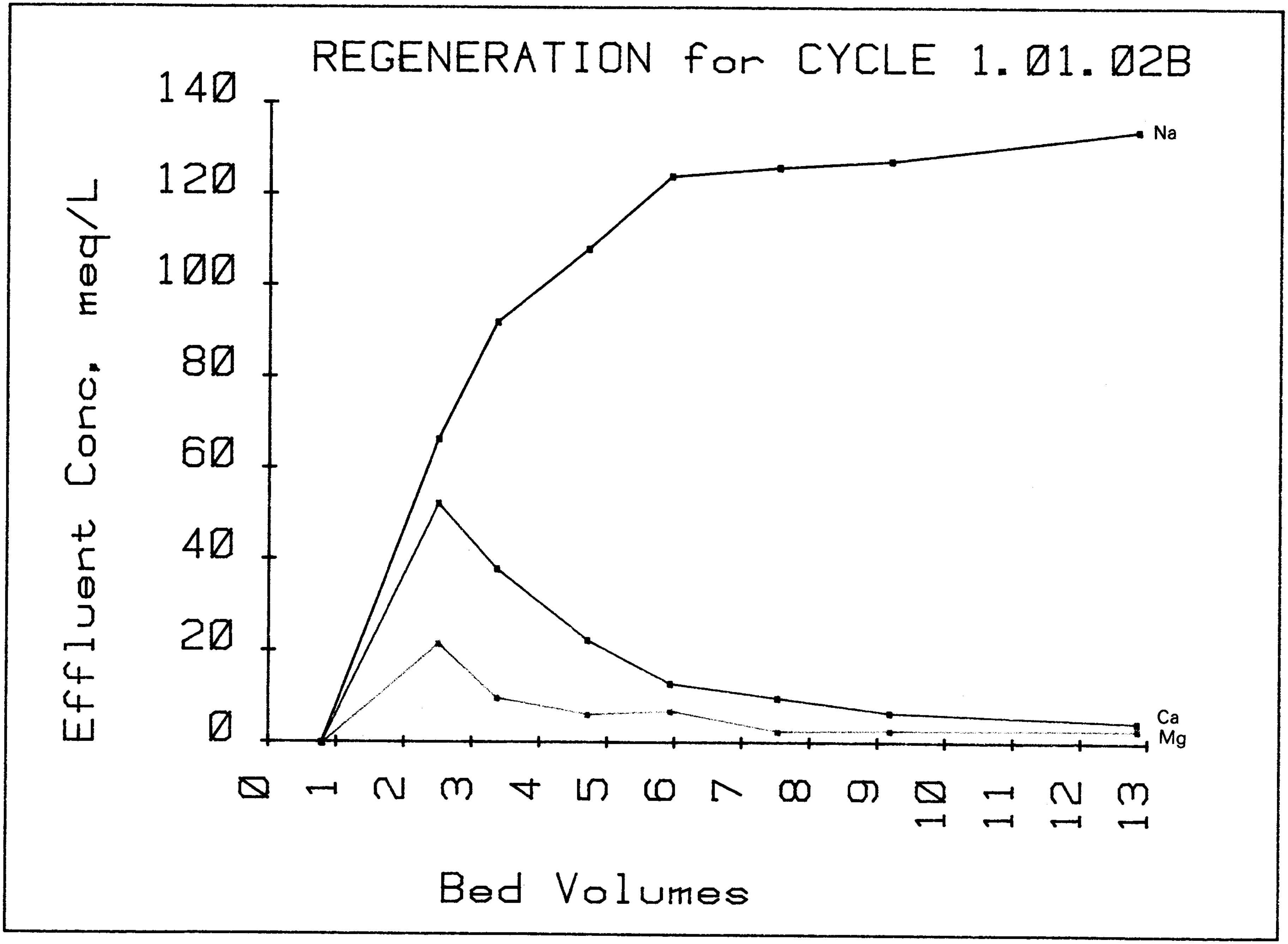
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.20	2.60	5.50
2	13.32	0.20	2.00	126.30
3	26.64	0.39	3.11	126.30
4	39.96	1.40	4.10	116.50
5	53.28	5.70	13.70	110.50
6	66.60	15.10	13.70	102.30
7	82.58	18.40	13.20	94.50
8	91.91	18.80	13.70	94.00
Influent		22.70	0.50	93.30
Conc Ratios (C/C0):				
1	0.30	0.01	5.20	0.06
2	13.32	0.01	4.00	1.35
3	26.64	0.02	6.22	1.35
4	39.96	0.06	8.20	1.25
5	53.28	0.25	27.40	1.18
6	66.60	0.67	27.40	1.10
7	82.58	0.81	26.40	1.01
8	91.91	0.83	27.40	1.01
Average effluent		7.05	8.22	104.12
Total resin capacity		1.43	-0.71	-0.99
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	53.71	6.00	13.70	110.24
Average effluent		1.28	4.43	107.03
Resin capacity		1.14	-0.21	-0.73
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	62.21	12.00	13.70	105.00
Average effluent		2.34	5.70	107.11
Resin capacity		1.26	-0.32	-0.86


EXHAUSTION for CYCLE 1.01.02X
Effluent Conc. meq/L
Bed Volumes
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Na
Ca
Mg

File 86

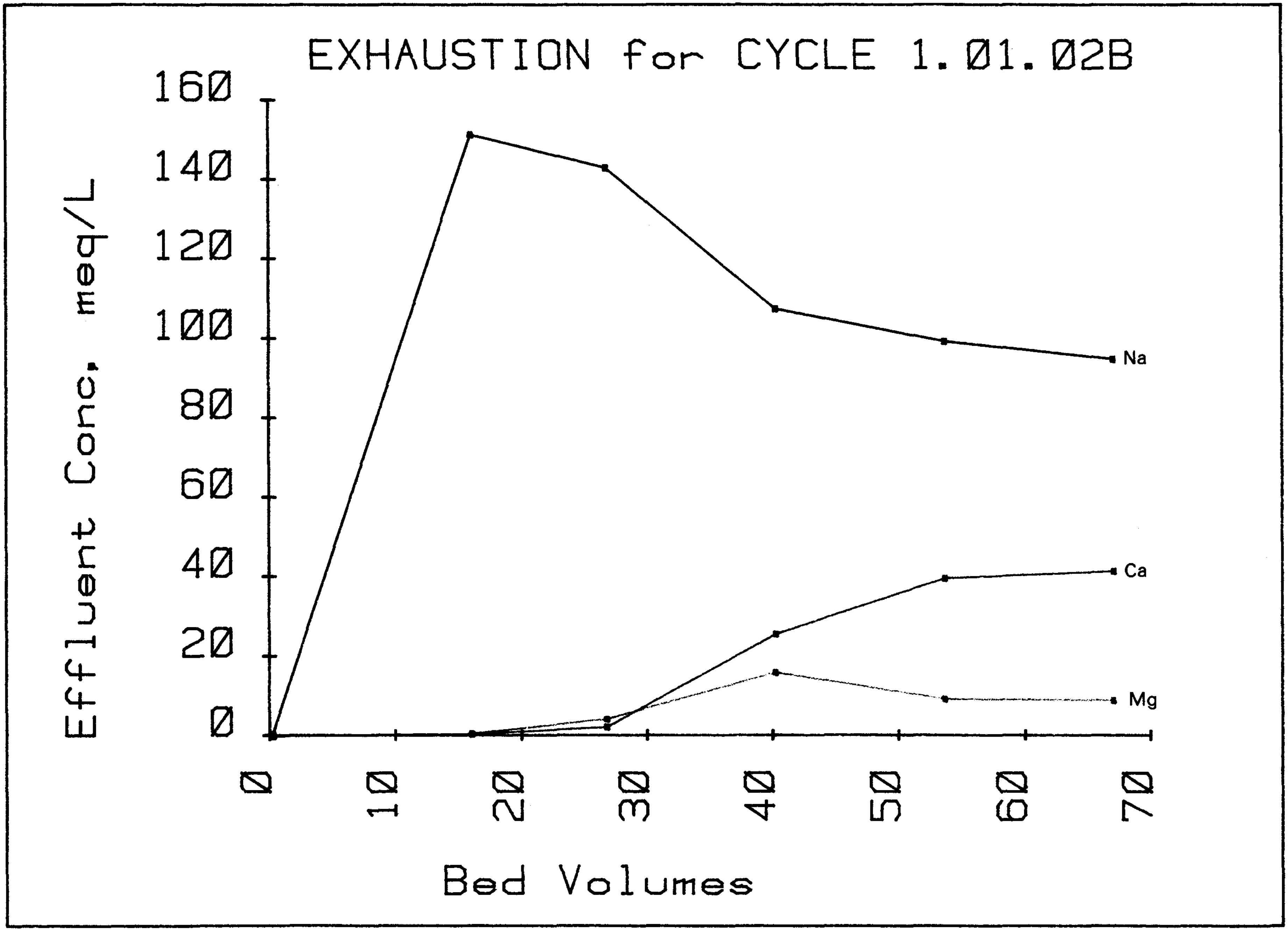
REGENERATION for CYCLE 1.01.02B Date: 7/25/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.80	0.15	0.00	1.83
2	2.51	522.40	217.60	664.00
3	3.37	374.00	99.00	920.00
4	4.71	223.70	63.33	1080.00
5	5.94	129.00	71.00	1248.00
6	7.53	98.00	27.00	1260.00
7	9.18	66.00	29.00	1274.00
8	12.85	46.00	31.00	1340.00
Influent		23.30	44.70	1340.00
Average effluent		163.59	62.07	1070.56
Total resin capacity		-1.69	-0.21	3.25


REGENERATION for CYCLE 1.01.02B
Effluent Conc. meq/L
140
120
100
80
60
40
20
0
Na
Ca
Mg
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Bed Volumes

EXHAUSTION for CYCLE 1.01.02B Date: 7/25/80

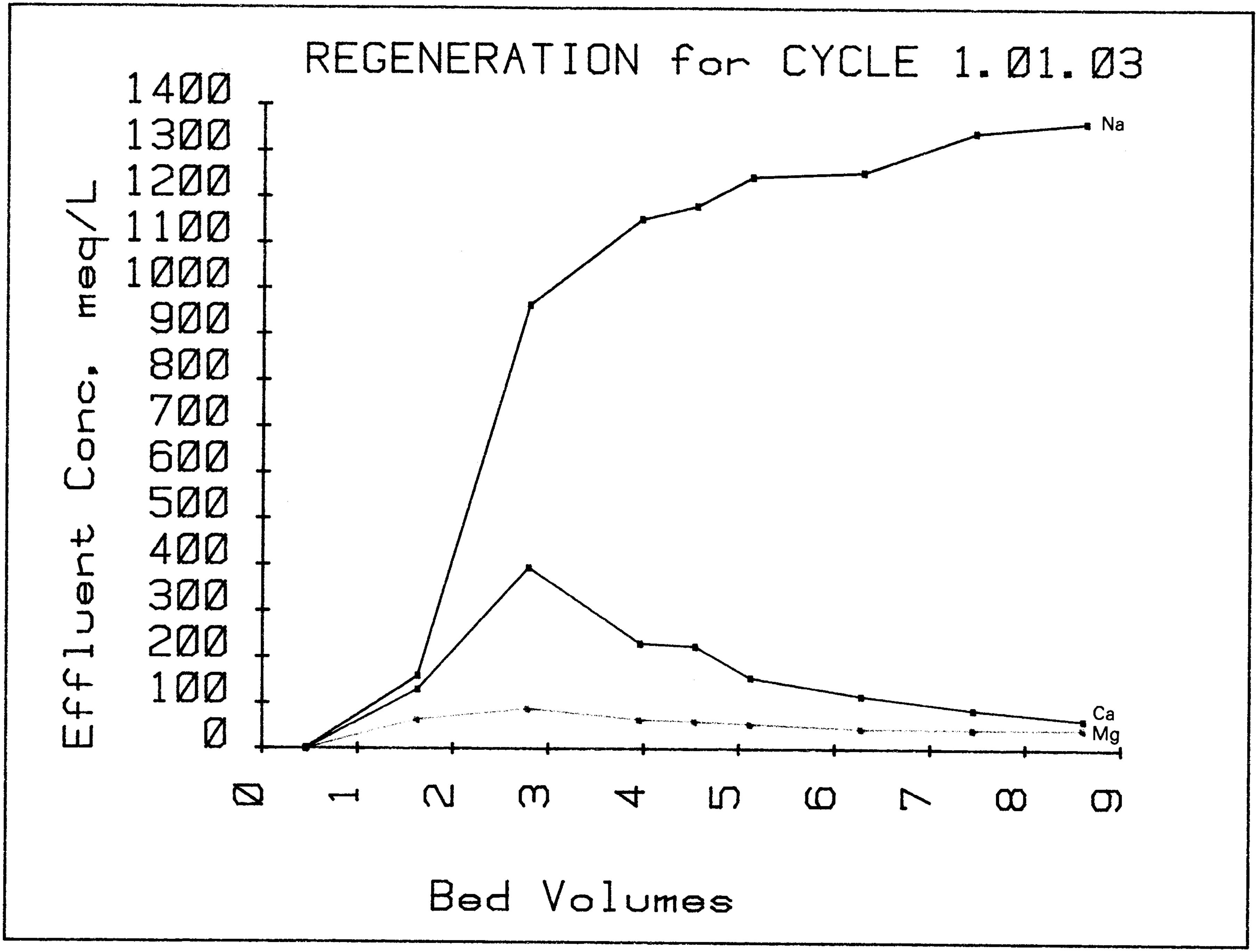
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.06	0.14	0.50
2	16.10	0.40	0.70	151.30
3	26.83	2.20	4.20	143.00
4	40.25	25.60	16.10	107.50
5	53.66	39.60	9.40	99.30
6	67.08	41.40	9.10	94.80
Influent		42.00	9.30	101.30
Conc Ratios (C/C0):				
1	0.30	0.00	0.02	0.00
2	16.10	0.01	0.08	1.49
3	26.83	0.05	0.45	1.41
4	40.25	0.61	1.73	1.06
5	53.66	0.94	1.01	0.98
6	67.08	0.99	0.98	0.94
Average effluent		17.74	6.95	107.04
Total resin capacity		1.62	0.16	-0.38
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	29.01	6.00	6.13	137.24
Average effluent		0.92	1.54	107.40
Resin capacity		1.18	0.22	-0.18
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	32.45	12.00	9.18	128.13
Average effluent		1.79	2.19	110.11
Resin capacity		1.29	0.23	-0.28


EXHAUSTION for CYCLE 1.01.02B
Effluent Conc. meq/L
0
20
40
60
80
100
120
140
160
Bed Volumes
0
10
20
30
40
50
60
70
Na
Ca
Mg

File 8

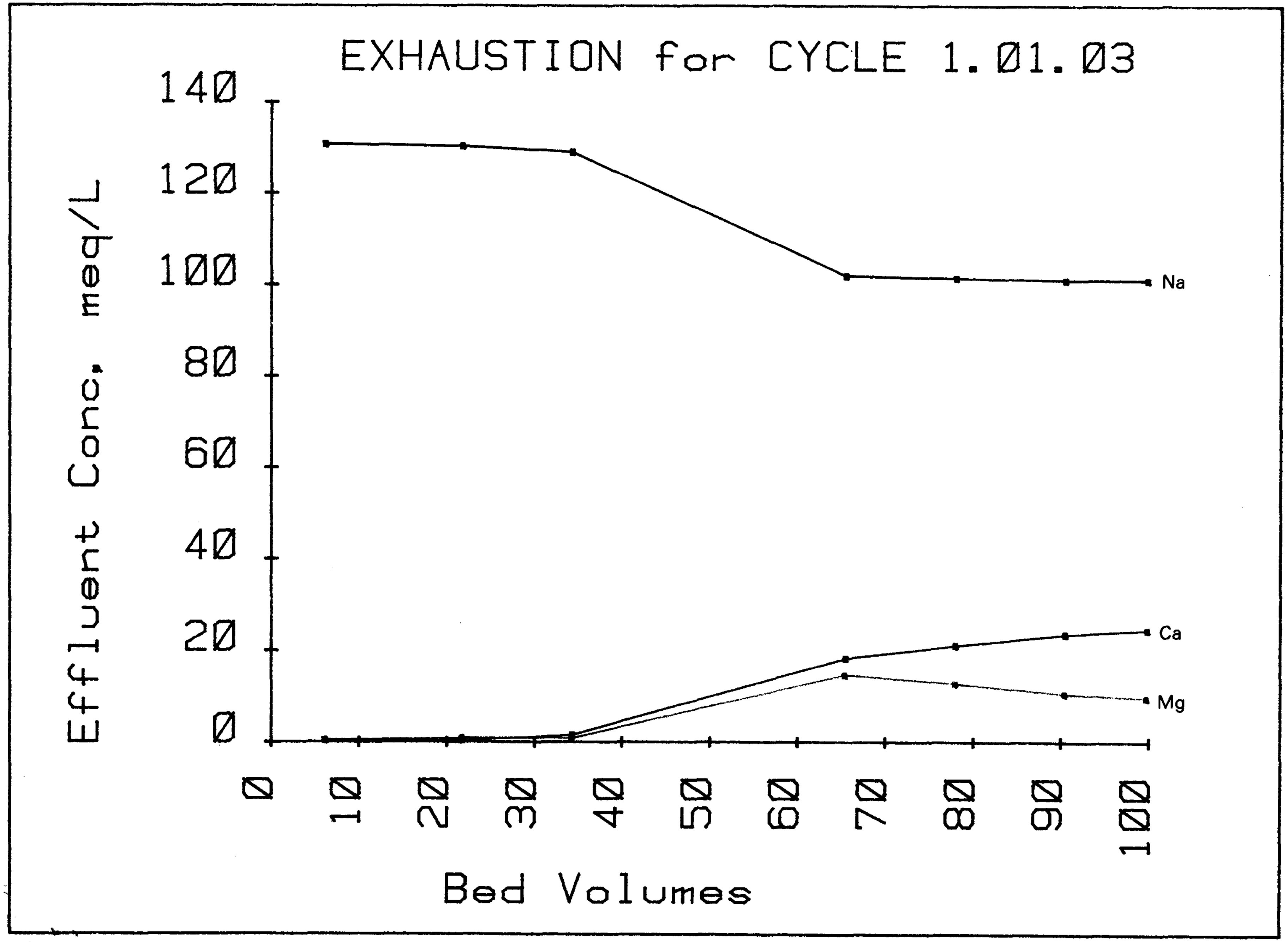
REGENERATION for CYCLE 1.01.03 Date: 7/21/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.47	0.10	0.30	1.54
2	1.63	130.00	64.00	160.00
3	2.79	394.00	88.00	962.00
4	3.96	230.00	64.00	1152.00
5	4.54	224.00	60.00	1180.00
6	5.12	156.00	54.00	1244.00
7	6.28	116.00	44.00	1254.00
8	7.45	86.00	43.00	1340.00
9	8.61	64.00	44.00	1362.00
Influent		24.00	44.00	1362.00
Average effluent		165.75	54.25	969.76
Total resin capacity		-1.15	-0.08	3.19


REGENERATION for CYCLE 1.01.03
Effluent Conc. meq/L
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
Bed Volumes
Na
Ca
Mg

EXHAUSTION for CYCLE 1.01.03 Date: 7/21/80

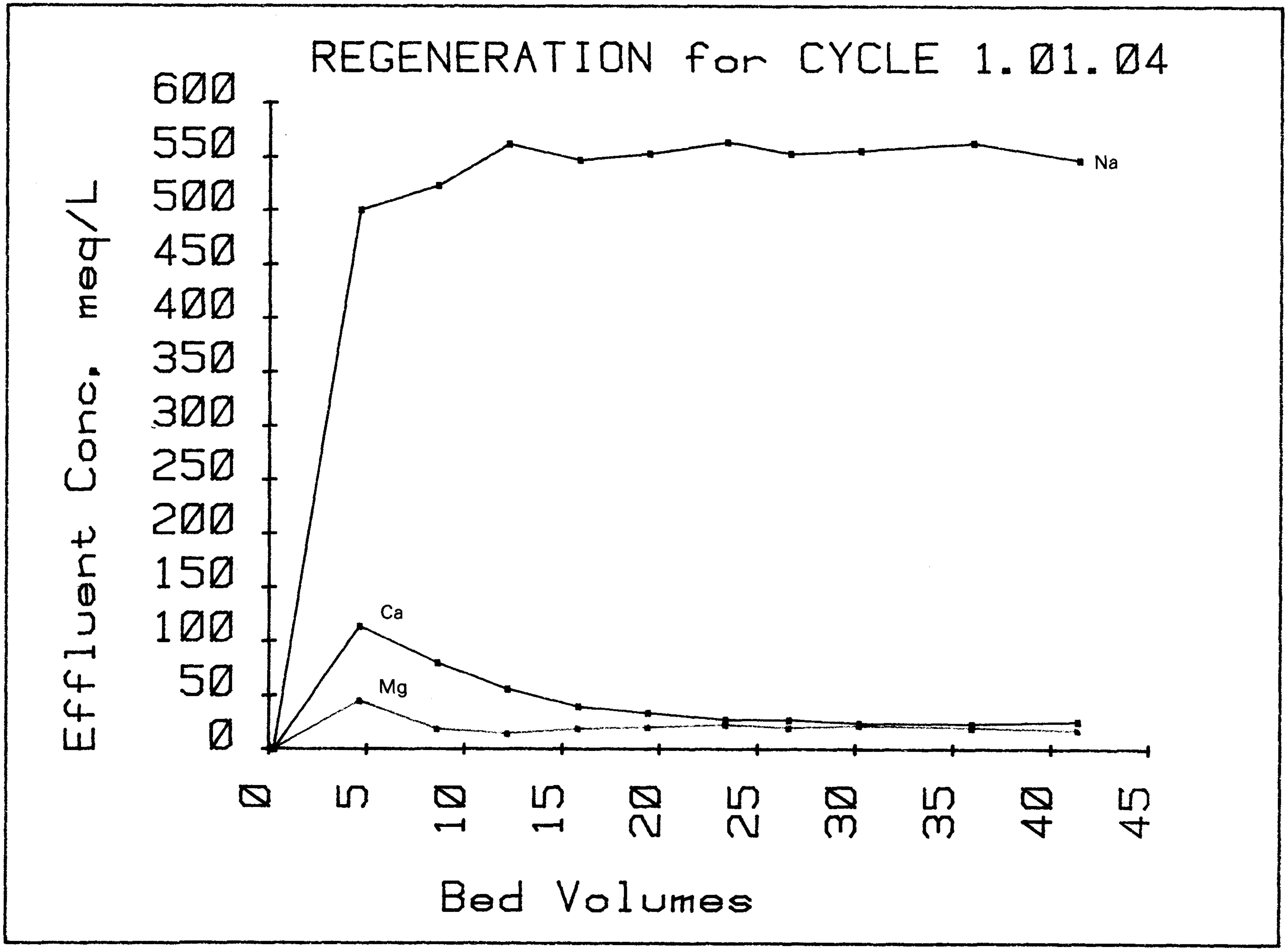
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	3.12	0.10	0.90	92.00
2	6.24	0.40	0.60	130.80
3	21.84	0.40	1.00	130.30
4	34.32	1.60	0.90	129.00
5	65.50	18.40	14.80	102.00
6	78.00	21.10	12.90	101.50
7	90.50	23.50	10.70	101.00
8	99.84	24.50	9.80	101.00
Influent		26.80	7.60	102.00
Conc Ratios (C/C0):				
1	3.12	0.00	0.12	0.90
2	6.24	0.01	0.08	1.28
3	21.84	0.01	0.13	1.28
4	34.32	0.06	0.12	1.26
5	65.50	0.69	1.95	1.00
6	78.00	0.79	1.70	1.00
7	90.50	0.88	1.41	0.99
8	99.84	0.91	1.29	0.99
Average effluent		11.18	7.11	114.60
Total resin capacity		1.51	0.05	-1.22
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	42.49	6.00	4.54	121.93
Average effluent		1.28	1.24	127.69
Resin capacity		1.00	0.25	-1.01
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	53.62	12.00	9.50	112.29
Average effluent		2.99	2.52	125.36
Resin capacity		1.20	0.26	-1.18


EXHAUSTION for CYCLE 1.01.03
Effluent Conc. meq/L
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Bed Volumes
Na
Ca
Mg

File 10

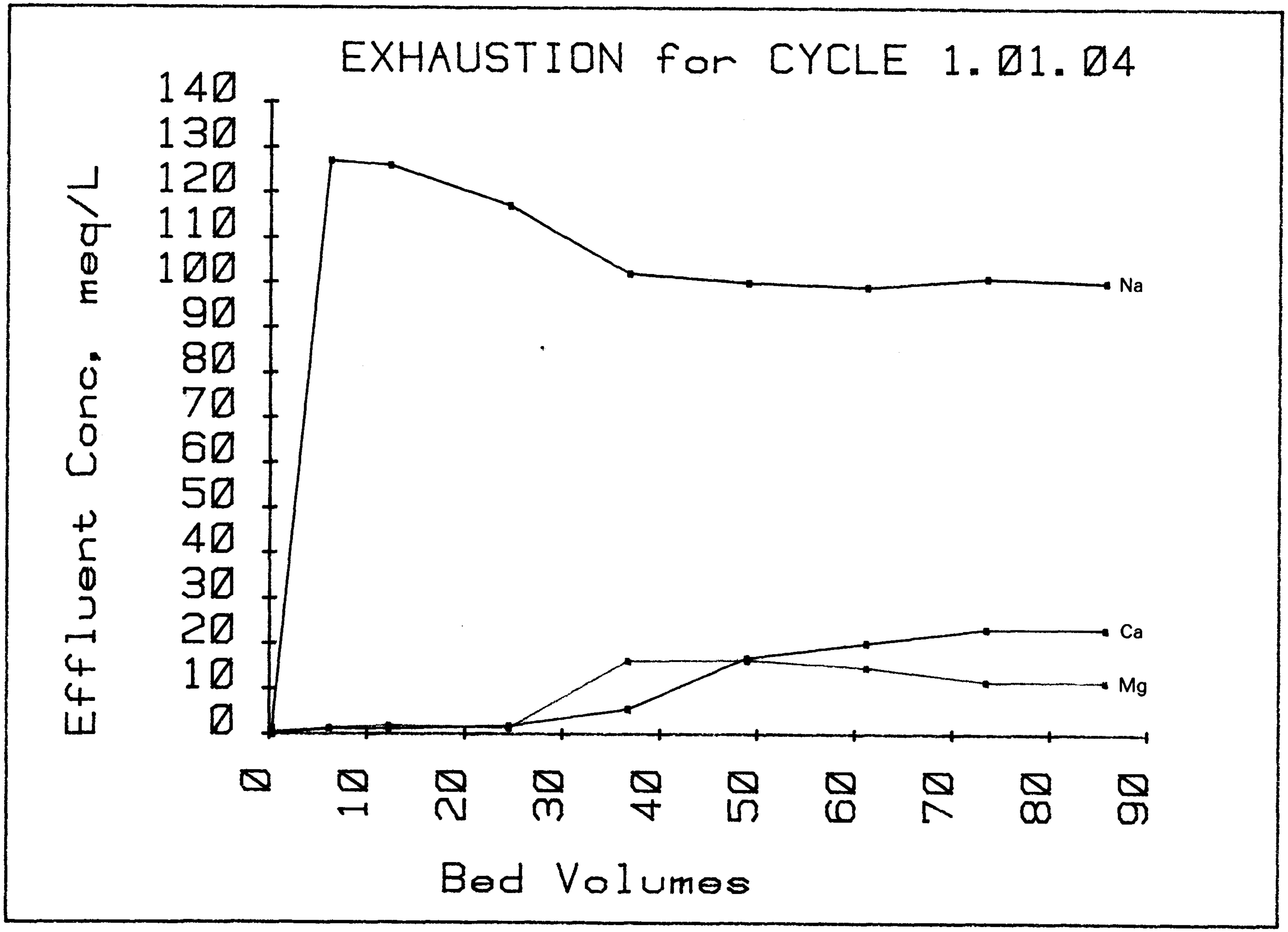
REGENERATION for CYCLE 1.01.04 Date: 7/23/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.10	1.17	1.59
2	4.68	114.00	46.00	500.00
3	8.64	80.00	19.80	523.00
4	12.24	56.00	15.60	562.00
5	15.84	40.00	20.00	547.00
6	19.44	34.00	21.40	553.00
7	23.40	28.00	23.70	564.00
8	26.64	27.80	20.80	553.00
9	30.24	24.80	23.00	556.00
10	36.00	24.30	21.00	563.00
11	41.40	26.40	18.70	547.00
Influent		22.20	23.10	577.00
Average effluent		43.09	22.14	518.01
Total resin capacity		-0.86	0.04	2.42


REGENERATION for CYCLE 1.01.04
Effluent Conc. meq/L
600
550
500
450
400
350
300
250
200
150
100
50
0
Na
Ca
Mg
0
5
10
15
20
25
30
35
40
45
Bed Volumes

EXHAUSTION for CYCLE 1.01.04 Date: 7/23/80

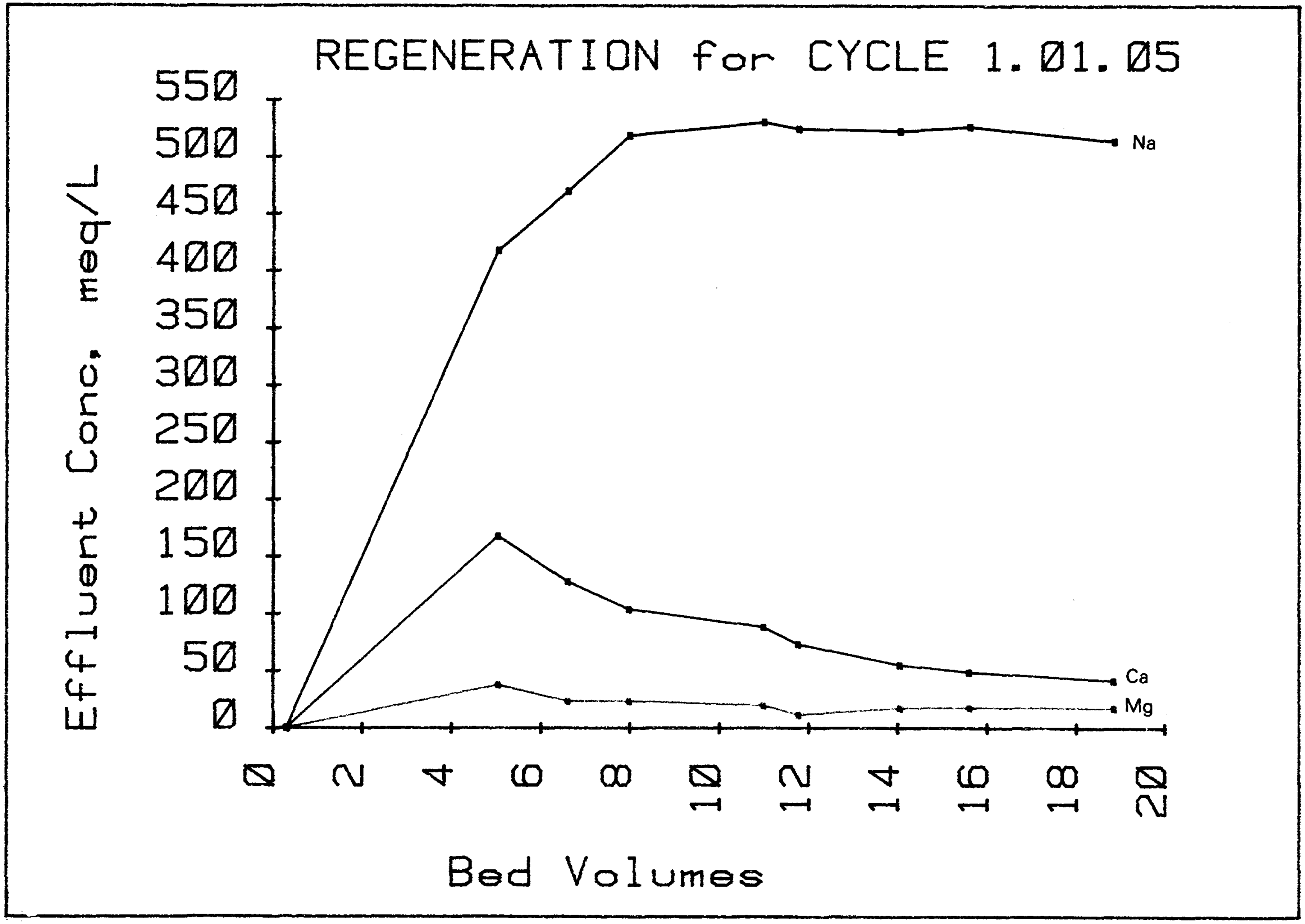
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.00	0.30	139.00
2	6.12	1.20	1.20	127.00
3	12.24	1.20	1.80	126.00
4	24.48	1.80	1.20	117.00
5	36.72	5.60	16.00	102.00
6	48.96	16.80	16.20	100.00
7	61.20	20.10	14.50	99.00
8	73.44	23.30	11.50	101.00
9	85.68	23.30	11.50	100.00
Influent		23.20	13.00	102.00
Conc Ratios (C/C0):				
1	0.30	0.00	0.02	1.36
2	6.12	0.05	0.09	1.25
3	12.24	0.05	0.14	1.24
4	24.48 ✓	0.08	0.09	1.15
5	36.72 ✓	0.24	1.23	1.00
6	48.96 ✓	0.72	1.25	0.98
7	61.20	0.87	1.12	0.97
8	73.44	1.00	0.88	0.99
9	85.68	1.00	0.88	0.98
Average effluent		11.57	9.63	108.74
Total resin capacity		0.99	0.29	-0.58
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	37.16	6.00	16.01	101.93
Average effluent		2.09	3.91	119.93
Resin capacity		0.78	0.33	-0.66
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	43.71	12.00	16.11	100.86
Average effluent		3.13	5.75	117.13
Resin capacity		0.87	0.31	-0.66


EXHAUSTION for CYCLE 1.01.04
Effluent Conc, meq/L
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
Bed Volumes
Na
Ca
Mg

File 12

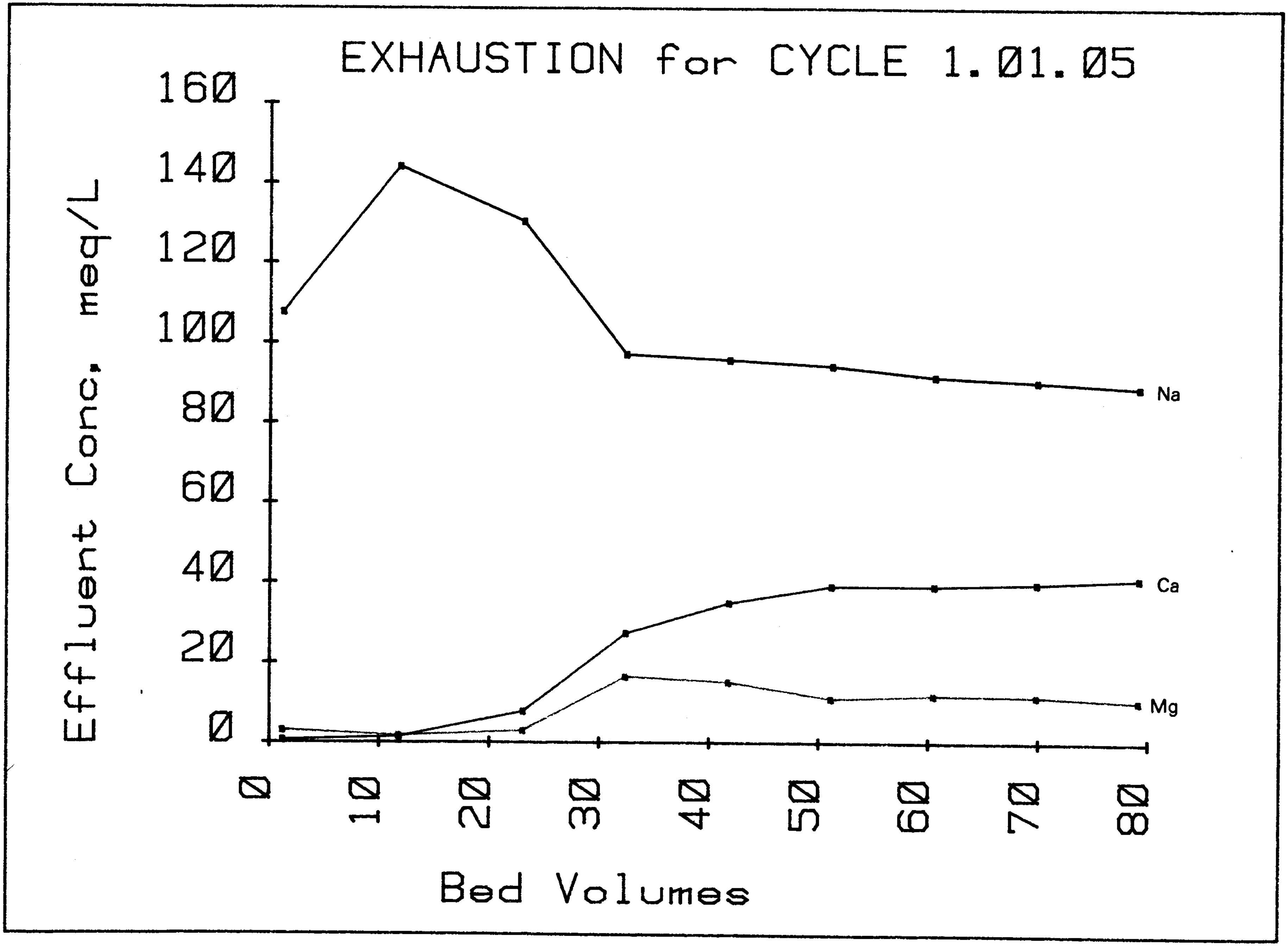
REGENERATION for CYCLE 1.01.05 Date: 7/28/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.30	2.70	1.10
2	5.04	168.00	37.60	418.00
3	6.60	128.80	23.40	470.00
4	7.98	104.00	23.40	519.00
5	10.98	84.60	19.60	531.00
6	11.76	73.60	11.60	525.00
7	14.04	55.40	17.40	523.00
8	15.60	49.20	18.00	527.00
9	18.84	42.00	17.40	514.00
Influent		22.20	22.60	584.00
Average effluent		81.55	19.96	434.48
Total resin capacity		-1.10	0.05	2.77


REGENERATION for CYCLE 1.01.05
Effluent Conc. meq/L
0
50
100
150
200
250
300
350
400
450
500
550
Na
Ca
Mg
0
2
4
6
8
10
12
14
16
18
20
Bed Volumes

EXHAUSTION for CYCLE 1.01.05 Date: 7/28/80

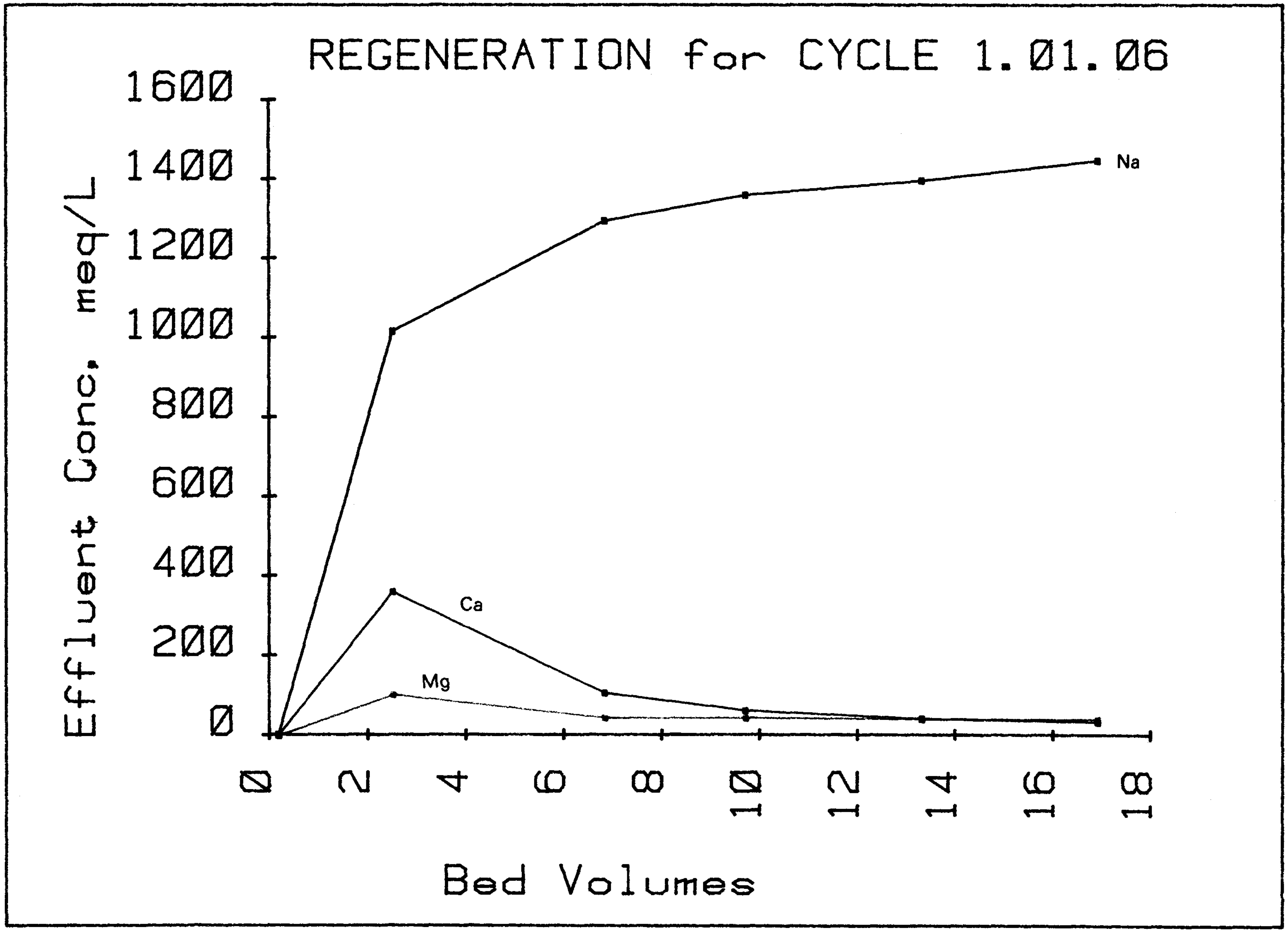
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	1.25	0.60	3.00	107.80
2	11.86	1.50	1.70	144.30
3	23.09	7.80	2.90	130.50
4	32.45	27.40	16.50	97.30
5	41.81	35.00	15.20	96.00
6	51.17	39.20	11.10	94.50
7	60.53	39.20	11.84	91.80
8	69.89	39.80	11.60	90.50
9	79.25	41.00	10.40	89.00
Influent		40.08	10.68	92.80
Conc Ratios (C/C0):				
1	1.25	0.01	0.28	1.16
2	11.86	0.04	0.16	1.55
3	23.09	0.19	0.27	1.41
4	32.45	0.68	1.54	1.05
5	41.81	0.87	1.42	1.03
6	51.17	0.98	1.04	1.02
7	60.53	0.98	1.11	0.99
8	69.89	0.99	1.09	0.98
9	79.25	1.02	0.97	0.96
Average effluent		25.41	9.40	106.51
Total resin capacity		1.14	0.10	-1.07
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	19.88	6.00	2.56	134.44
Average effluent		2.21	2.25	131.79
Resin capacity		0.71	0.16	-0.73
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	25.10	12.00	5.81	123.39
Average effluent		3.49	2.50	131.47
Resin capacity		0.87	0.20	-0.92


EXHAUSTION for CYCLE 1.01.05
Effluent Conc. meq/L
Bed Volumes
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
Na
Ca
Mg

File 14

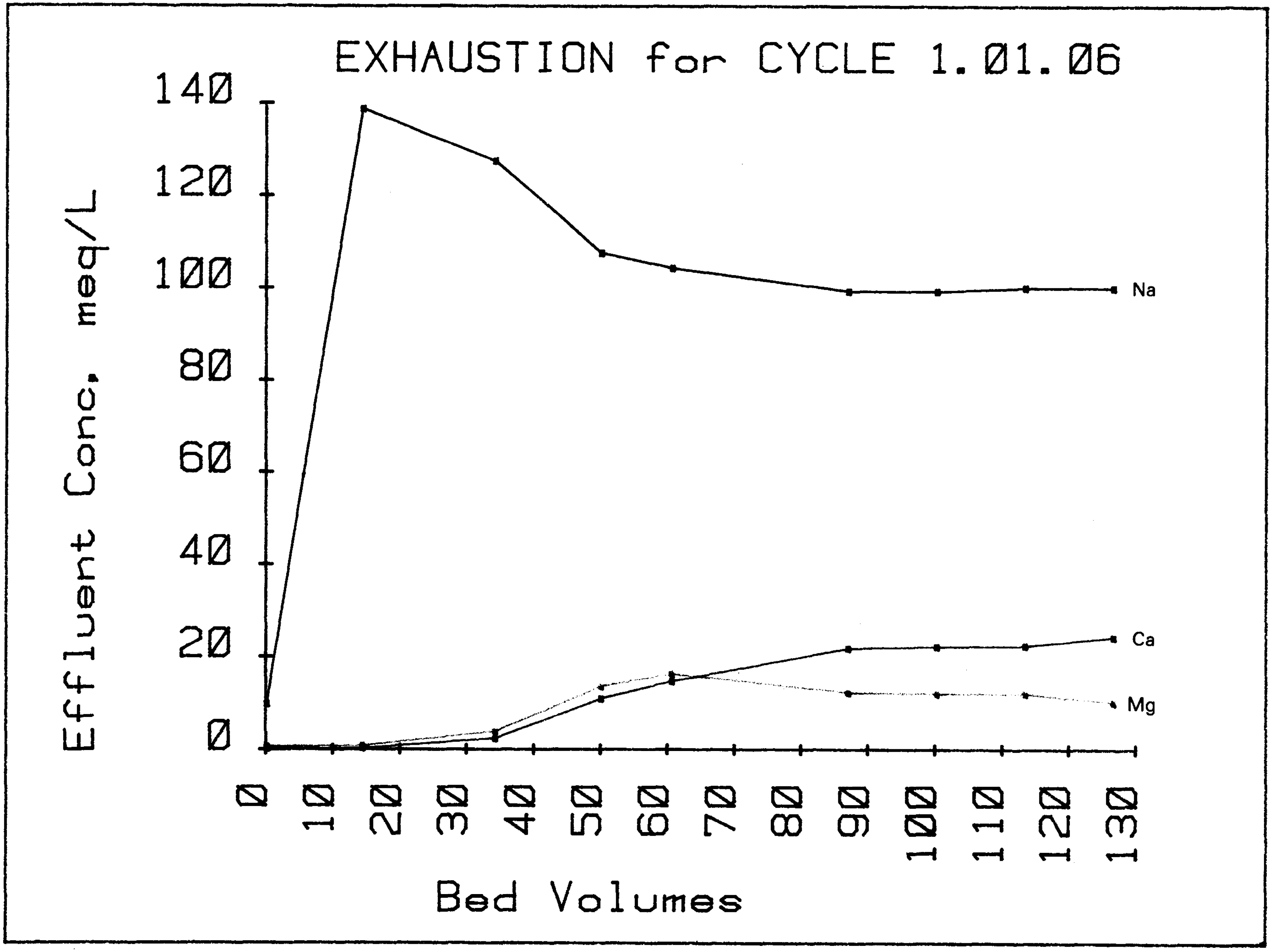
REGENERATION for CYCLE 1.01.06 Date: 7/18/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.20	0.10	0.40	1.29
2	2.52	360.00	103.00	1016.00
3	6.84	106.00	45.00	1294.00
4	9.72	62.00	45.00	1360.00
5	13.32	42.00	42.00	1396.00
6	16.92	34.00	42.00	1446.00
Influent		24.00	36.00	1428.00
Average effluent		119.03	52.45	1200.23
Total resin capacity		-1.59	-0.28	3.81


REGENERATION for CYCLE 1.01.06
Effluent Conc. meq/L
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
16
18
Bed Volumes
Na
Ca
Mg

EXHAUSTION for CYCLE 1.01.06 Date: 7/18/80

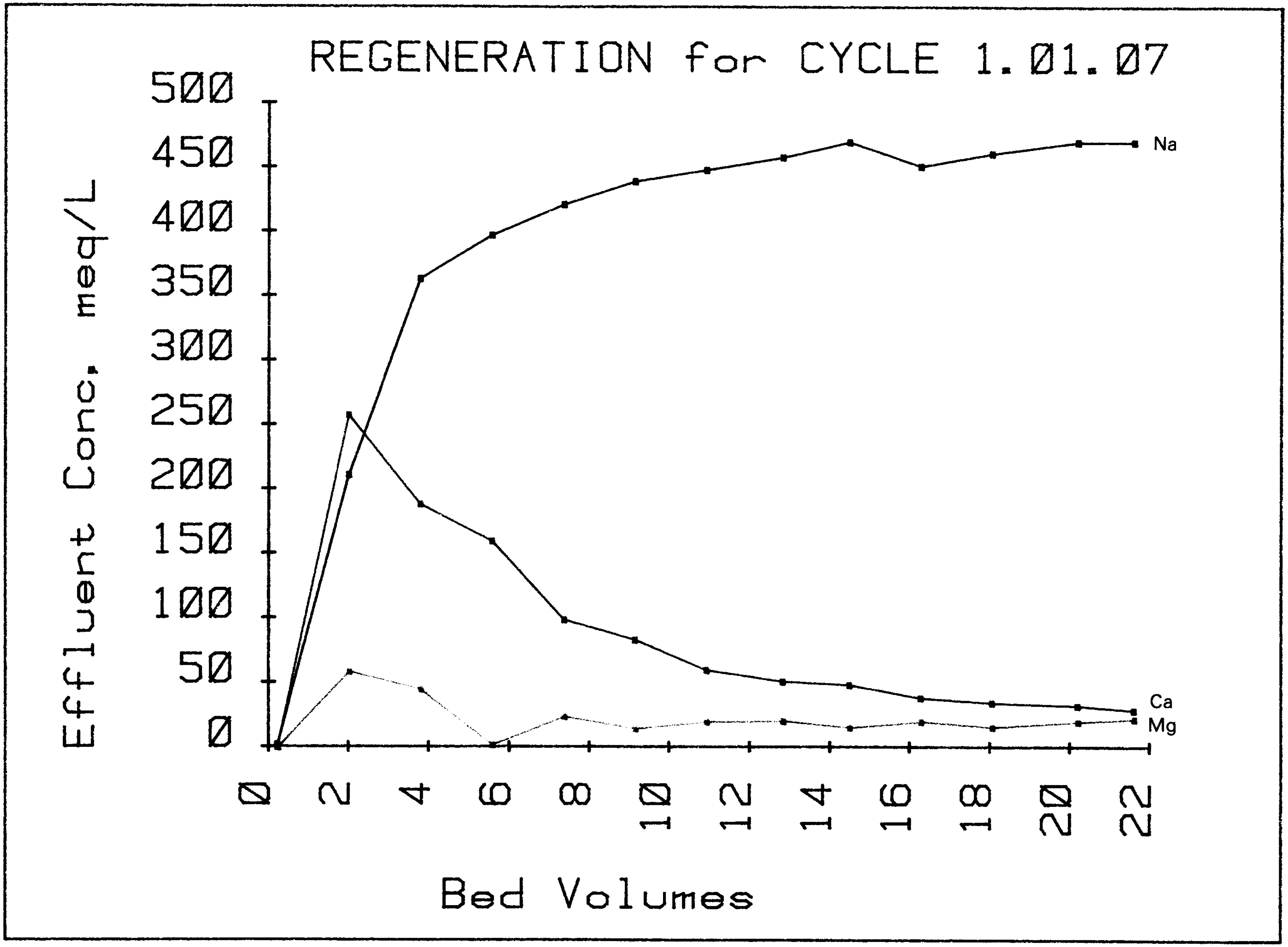
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.10	0.50	10.00
2	14.52	0.20	0.70	138.80
3	34.32	2.40	3.80	127.50
4	50.16	11.00	13.50	107.50
5	60.72	14.70	16.20	104.30
6	87.12	21.80	12.20	99.30
7	100.32	22.20	12.00	99.30
8	113.52	22.40	12.00	100.00
9	126.72	24.40	10.20	100.00
Influent		23.40	12.20	102.00
Conc Ratios (C/C0):				
1	0.30	0.00	0.04	0.10
2	14.52	0.01	0.06	1.36
3	34.32	0.10	0.31	1.25
4	50.16	0.47	1.11	1.05
5	60.72	0.63	1.33	1.02
6	87.12	0.93	1.00	0.97
7	100.32	0.95	0.98	0.97
8	113.52	0.96	0.98	0.98
9	126.72	1.04	0.84	0.98
Average effluent		13.01	9.38	105.26
Total resin capacity		1.31	0.36	-0.41
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	40.95	6.00	7.86	119.13
Average effluent		1.37	2.26	110.99
Resin capacity		0.90	0.40	-0.37
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	53.01	12.00	14.23	106.64
Average effluent		3.16	4.36	111.19
Resin capacity		1.07	0.41	-0.48


EXHAUSTION for CYCLE 1.01.06
Effluent Conc. meq/L
0
20
40
60
80
100
120
140
Bed Volumes
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Na
Ca
Mg

File 16

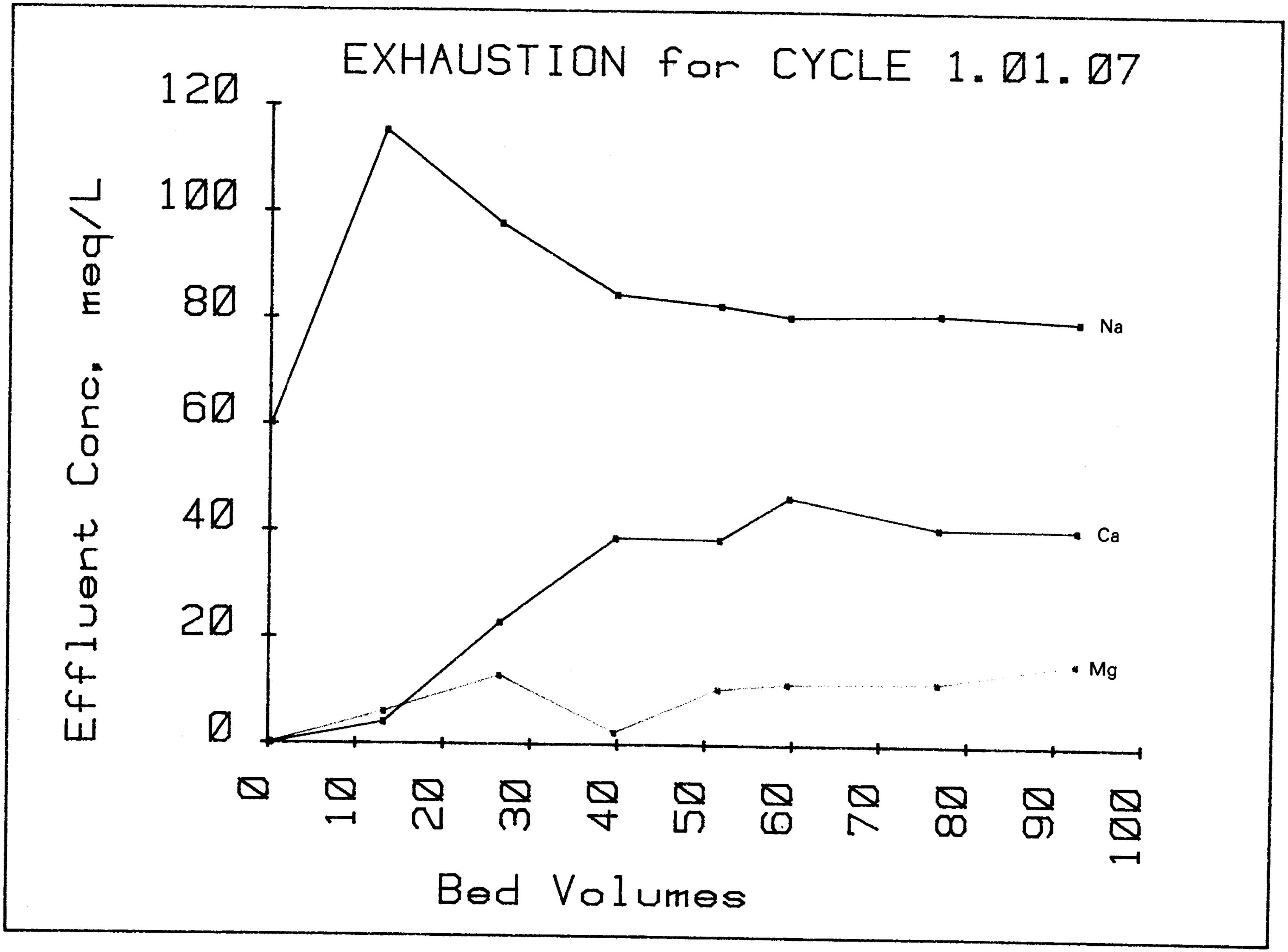
REGENERATION for CYCLE 1.01.07 Date: 7/29/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.24	0.19	0.10	1.87
2	2.02	257.60	59.00	211.00
3	3.80	188.40	45.20	363.00
4	5.58	159.80	2.00	397.00
5	7.37	98.80	24.00	421.00
6	9.15	83.20	14.60	439.00
7	10.93	59.80	20.40	448.00
8	12.83	51.00	20.60	458.00
9	14.49	48.40	15.60	470.00
10	16.28	38.40	20.20	451.00
11	18.06	34.60	16.00	461.00
12	20.20	32.40	20.20	470.00
13	21.62	29.00	22.40	470.00
Influent		22.40	21.70	486.00
Average effluent		88.99	22.37	401.97
Total resin capacity		-1.42	-0.01	1.80


REGENERATION for CYCLE 1.01.07
Effluent Conc. meq/L
500
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
22
Bed Volumes
Na
Ca
Mg

EXHAUSTION for CYCLE 1.01.07 Date: 7/29/80

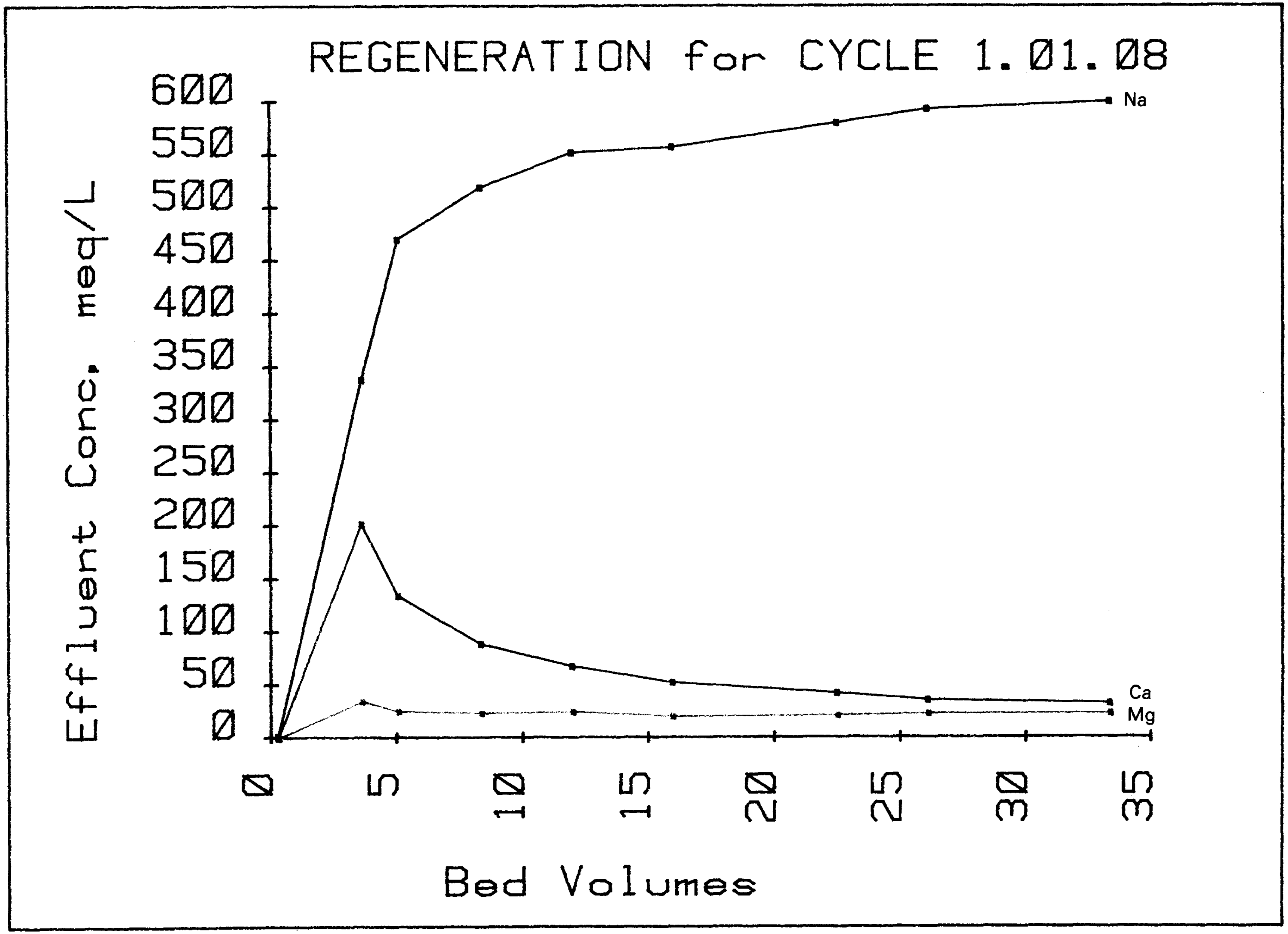
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.10	0.00	60.30
2	13.20	3.98	5.92	115.30
3	26.40	22.76	12.76	97.80
4	39.60	38.64	2.16	84.50
5	51.48	38.40	10.40	82.50
6	59.40	46.40	11.40	80.50
7	76.56	40.70	11.70	81.00
8	92.40	40.60	15.60	79.80
Influent		41.60	11.60	80.00
Conc Ratios (C/C0):				
1	0.30	0.00	0.00	0.75
2	13.20	0.10	0.51	1.44
3	26.40	0.55	1.10	1.22
4	39.60	0.93	0.19	1.06
5	51.48	0.92	0.90	1.03
6	59.40	1.12	0.98	1.01
7	76.56	0.98	1.01	1.01
8	92.40	0.98	1.34	1.00
Average effluent		30.32	9.07	87.28
Total resin capacity		1.04	0.23	-0.67
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	14.62	6.00	6.66	113.42
Average effluent		2.33	3.29	90.43
Resin capacity		0.56	0.12	-0.15
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	18.84	12.00	8.84	107.83
Average effluent		3.85	4.30	95.03
Resin capacity		0.70	0.14	-0.28


EXHAUSTION for CYCLE 1.01.07
Effluent Conc. meq/L
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
Bed Volumes
Na
Ca
Mg

File 18

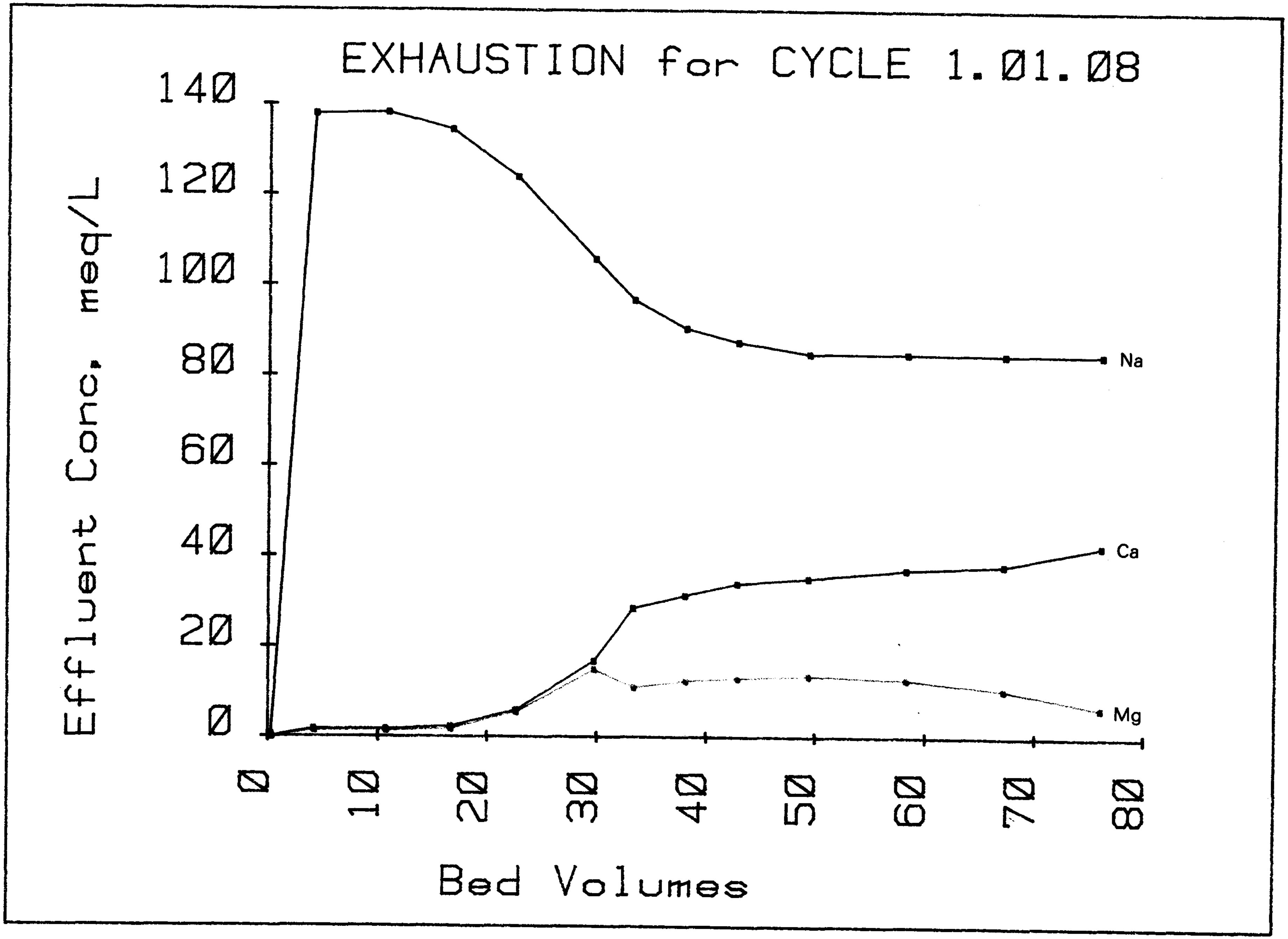
REGENERATION for CYCLE 1.01.08 Date: 7/30/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.00	0.46	1.47
2	3.62	202.00	35.20	338.00
3	5.07	134.40	25.60	470.00
4	8.34	89.00	23.80	519.00
5	11.96	68.00	25.00	552.00
6	15.95	52.60	20.40	557.00
7	22.47	42.40	21.60	580.00
8	26.09	36.00	23.20	593.00
9	33.34	32.80	23.20	600.00
Influent		18.00	22.80	643.00
Average effluent		65.69	22.67	516.70
Total resin capacity		-1.58	0.00	4.17


REGENERATION for CYCLE 1.01.08
Effluent Conc. meq/L
600
550
500
450
400
350
300
250
200
150
100
50
0
Na
Ca
Mg
0
5
10
15
20
25
30
35
Bed Volumes

EXHAUSTION for CYCLE 1.01.08 Date: 7/30/80

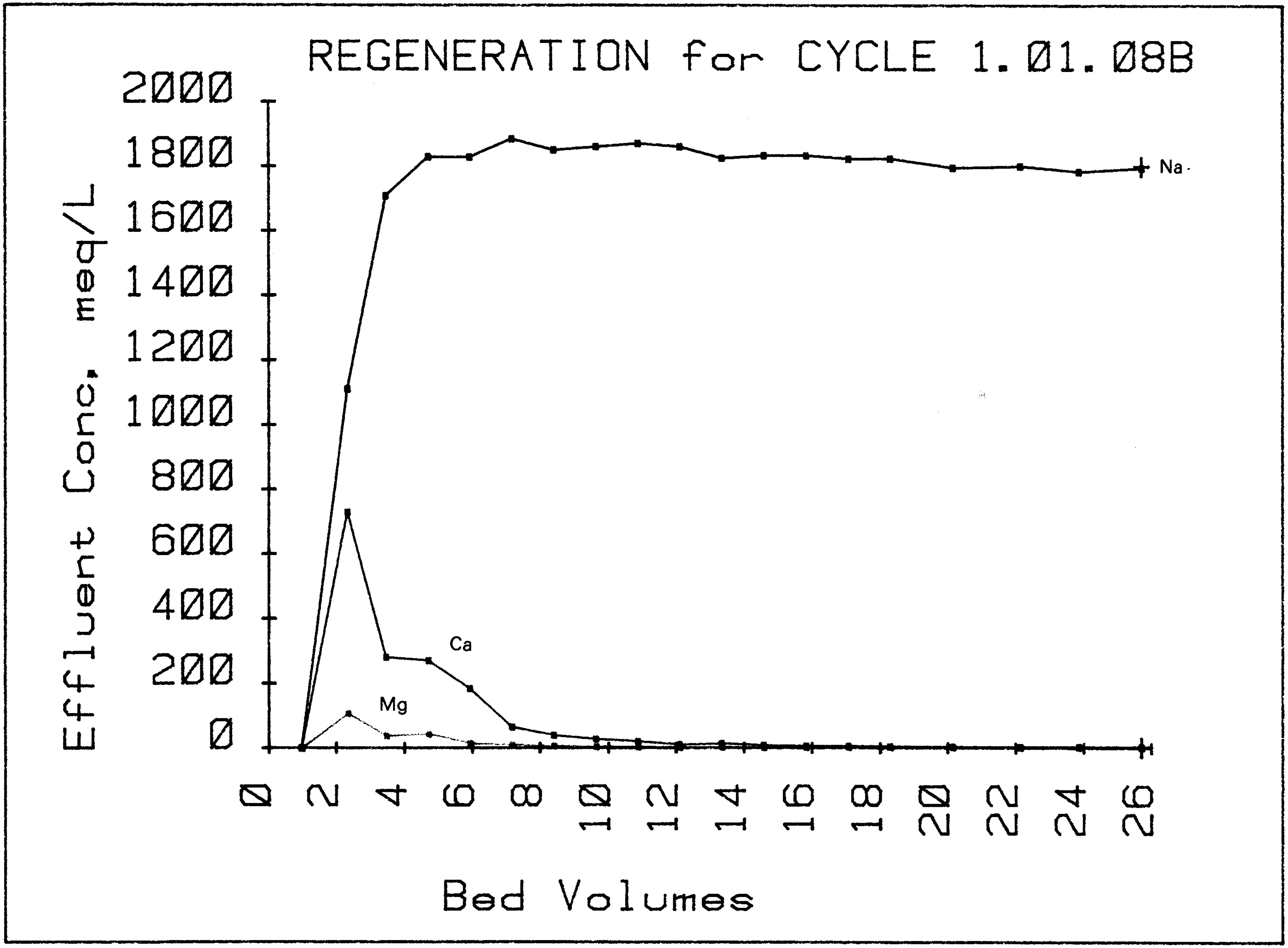
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.30	0.10	0.02	0.61
2	4.16	1.80	1.32	138.00
3	10.69	1.80	1.34	138.30
4	16.63	2.40	1.80	134.50
5	22.57	6.00	5.50	124.00
6	29.70	16.90	15.00	105.80
7	33.26	28.60	11.00	96.80
8	38.02	31.40	12.50	90.50
9	42.77	34.00	13.10	87.50
10	49.30	35.20	13.60	85.00
11	58.21	37.20	12.80	85.00
12	67.12	38.20	10.60	84.80
13	76.03	42.50	6.60	84.80
Influent		40.20	11.20	93.50
Conc Ratios (C/C0):				
1	0.30	0.00	0.00	0.01
2	4.16	0.04	0.12	1.48
3	10.69	0.04	0.12	1.48
4	16.63	0.06	0.16	1.44
5	22.57	0.15	0.49	1.33
6	29.70	0.42	1.34	1.13
7	33.26	0.71	0.98	1.04
8	38.02	0.78	1.12	0.97
9	42.77	0.85	1.17	0.94
10	49.30	0.88	1.21	0.91
11	58.21	0.93	1.14	0.91
12	67.12	0.95	0.95	0.91
13	76.03	1.06	0.59	0.91
Average effluent		23.21	8.77	100.73
Total resin capacity		1.29	0.18	-0.55
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	22.57	6.00	5.50	124.00
Average effluent		2.37	1.90	123.38
Resin capacity		0.84	0.21	-0.67
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	26.49	12.00	10.73	113.98
Average effluent		3.37	2.83	122.72
Resin capacity		0.96	0.22	-0.77


EXHAUSTION for CYCLE 1.01.08
Effluent Conc, meq/L
Bed Volumes
Na
Ca
Mg
0
20
40
60
80
100
120
140
0
10
20
30
40
50
60
70
80

File 20

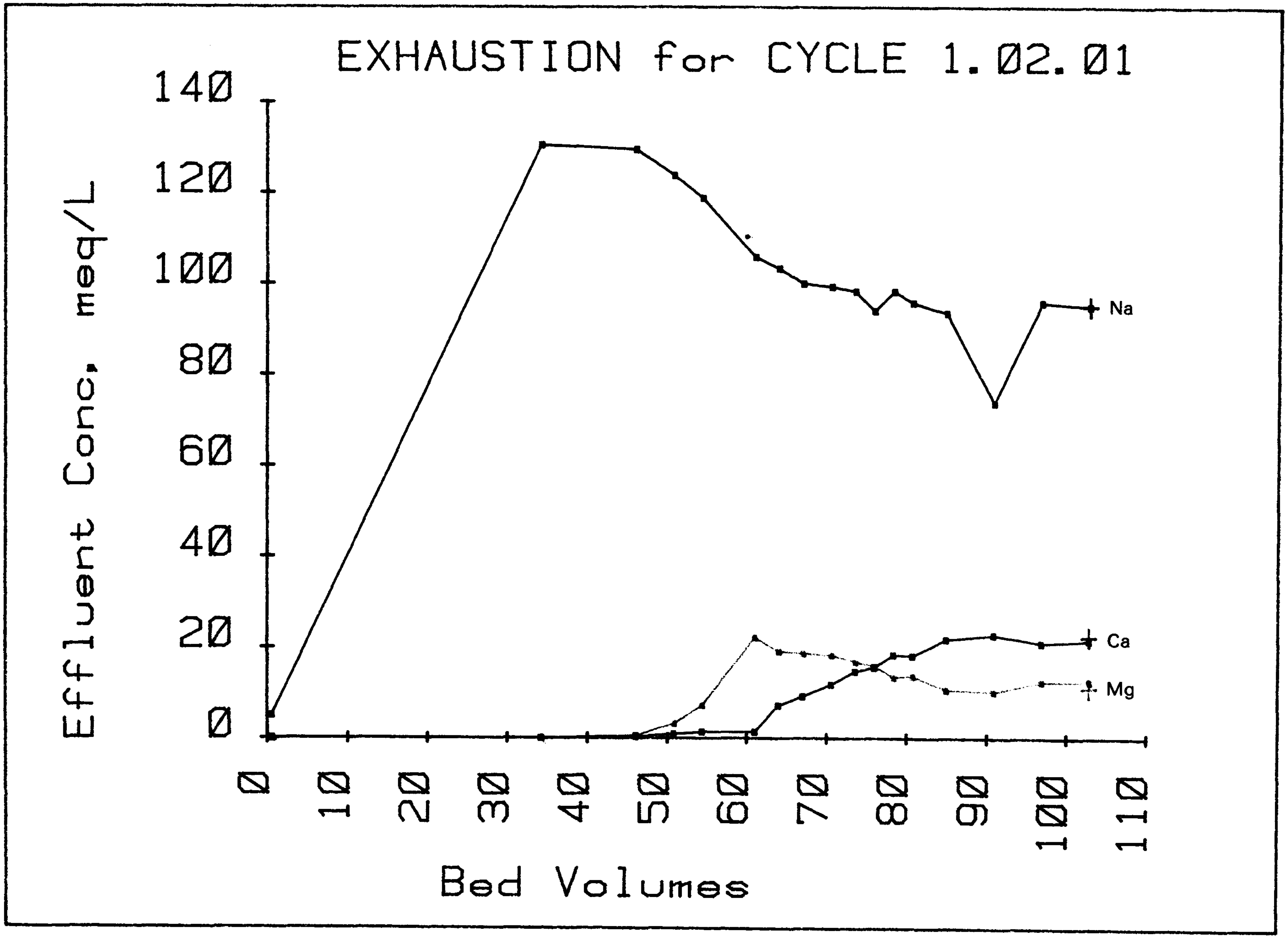
REGENERATION for CYCLE 1.01.08B Date: 7/31/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.99	0.00	0.02	0.48
2	2.35	729.00	107.00	1110.00
3	3.46	280.00	38.00	1708.00
4	4.70	270.00	44.00	1828.00
5	5.93	183.00	14.00	1828.00
6	7.17	64.20	9.60	1885.00
7	8.40	38.80	6.40	1850.00
8	9.64	27.20	4.40	1860.00
9	10.88	20.08	3.96	1870.00
10	12.11	10.24	2.16	1860.00
11	13.35	13.80	2.40	1825.00
12	14.58	7.82	1.90	1833.00
13	15.82	6.40	2.34	1833.00
14	17.06	5.78	1.98	1823.00
15	18.29	5.08	1.24	1823.00
16	20.15	3.60	2.00	1795.00
17	22.12	3.30	1.38	1800.00
18	23.85	3.40	1.54	1783.00
19	25.71	3.34	1.55	1795.00
Influent		2.80	1.97	1800.00
Average effluent		83.29	12.31	1736.03
Total resin capacity		-1.99	-0.26	1.58


REGENERATION for CYCLE 1.01.08B
Effluent Conc, meq/L
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Na
Ca
Mg
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Bed Volumes

EXHAUSTION for CYCLE 1.02.01 Date: 8/7/80

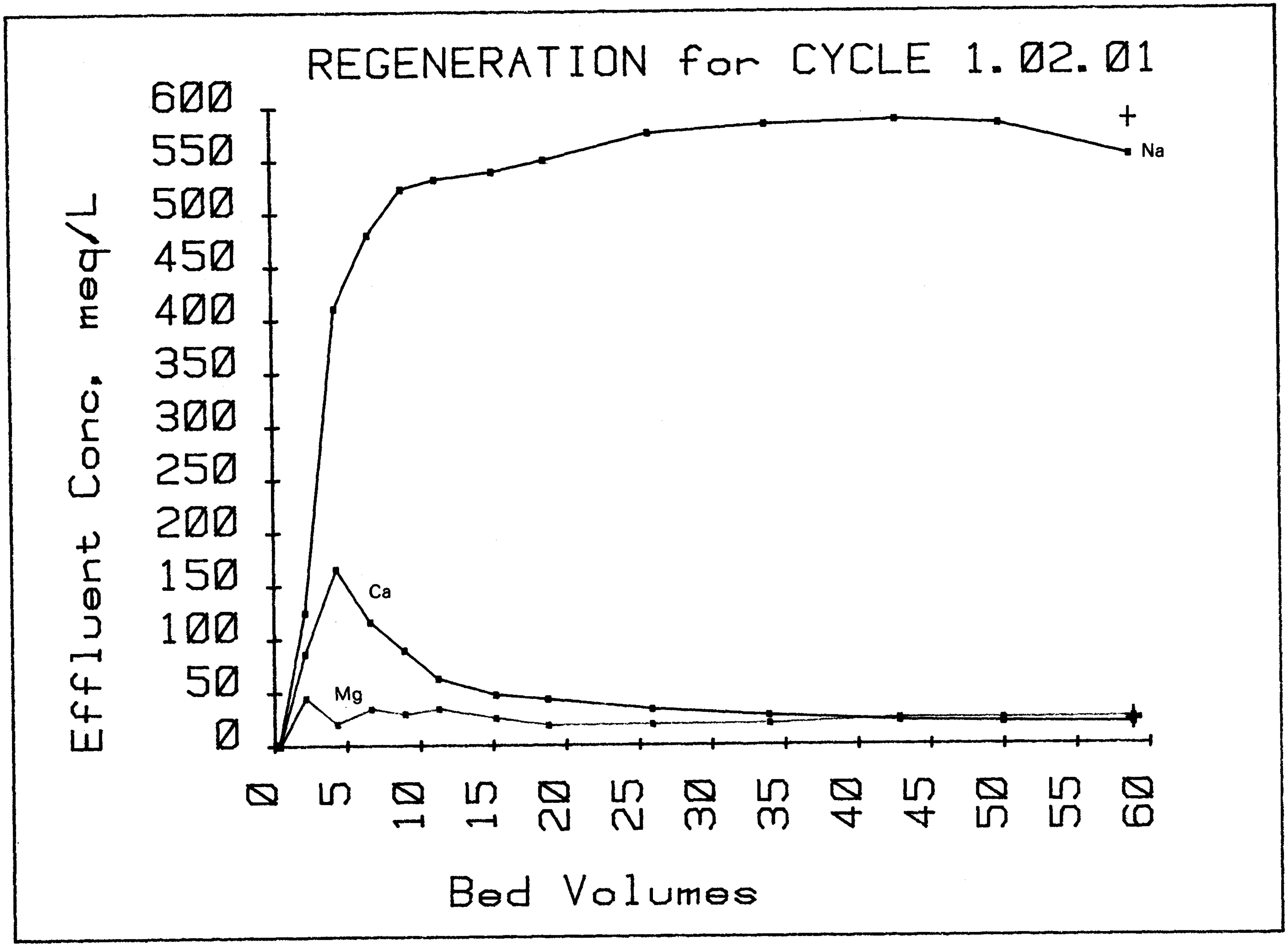
OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.60	0.00	0.00	5.00
2	34.26	0.02	0.05	130.50
3	46.02	0.30	0.66	129.50
4	50.80	0.90	3.30	123.80
5	54.38	1.38	7.32	118.80
6	60.96	1.34	22.26	105.80
7	63.94	7.20	19.20	103.30
8	66.93	9.24	18.76	100.00
9	70.52	11.84	18.36	99.30
10	73.51	14.80	17.00	98.30
11	75.90	15.60	16.00	94.00
12	78.29	18.40	13.60	98.30
13	80.68	18.20	13.80	95.80
14	84.86	21.80	10.80	93.50
15	90.84	22.80	10.40	73.80
16	96.81	21.00	12.60	95.80
17	102.79	21.60	12.60	95.00
Influent		22.40	11.20	95.00
Conc Ratios (C/C0):				
1	0.60	0.00	0.00	0.05
2	34.26	0.00	0.00	1.37
3	46.02	0.01	0.06	1.36
4	50.80	0.04	0.29	1.30
5	54.38	0.06	0.65	1.25
6	60.96	0.06	1.99	1.11
7	63.94	0.32	1.71	1.09
8	66.93	0.41	1.68	1.05
9	70.52	0.53	1.64	1.05
10	73.51	0.66	1.52	1.03
11	75.90	0.70	1.43	0.99
12	78.29	0.82	1.21	1.03
13	80.68	0.81	1.23	1.01
14	84.86	0.97	0.96	0.98
15	90.84	1.02	0.93	0.78
16	96.81	0.94	1.13	1.01
17	102.79	0.96	1.13	1.00
Average effluent		7.13	7.19	93.17
Total resin capacity		1.56	0.41	0.19
At Breakthrough point of		6.00 meq-Ca/L		
Effluent	63.33	6.00	19.83	103.81
Average effluent		0.43	2.88	93.04
Resin capacity		1.38	0.52	0.12
At Breakthrough point of		12.00 meq-Ca/L		
Effluent	70.68	12.00	18.29	99.25
Average effluent		1.36	4.55	93.85
Resin capacity		1.47	0.47	0.08


EXHAUSTION for CYCLE 1.02.01
Effluent Conc. meq/L
0
20
40
60
80
100
120
140
Bed Volumes
0
10
20
30
40
50
60
70
80
90
100
110
Na
Ca
Mg

FILE 22

REGENERATION for CYCLE 1.02.01 Date: 8/7/80

OBS #	BED VOLS	Ca meq/L	Mg meq/L	Na meq/L
1	0.36	0.00	0.10	1.57
2	2.14	86.40	45.40	125.00
3	4.28	166.00	21.00	411.00
4	6.59	116.00	35.00	480.00
5	8.91	89.20	30.00	523.00
6	11.23	62.60	34.80	532.00
7	15.15	47.60	26.00	539.00
8	18.71	43.20	19.20	550.00
9	25.84	33.60	19.80	575.00
10	33.86	27.60	20.40	583.00
11	42.78	22.40	25.40	587.00
12	49.90	21.00	25.00	583.00
13	56.81	20.00	25.80	553.00
Influent		22.40	25.40	587.00
Average effluent		43.52	24.58	534.45
Total resin capacity		-1.23	0.05	3.07


REGENERATION for CYCLE 1.02.01
Effluent Conc. meq/L
600
550
500
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
55
60
Bed Volumes
Na
Ca
Mg

APPENDIX G

Equilibrium-Model Calculations of Specific Resin Capacities and Initial Exhaustion-Effluent Compositions for Field and Laboratory IX Cycles

L.01.97

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .614477 eq/L

K[Ca/Na]*Q/Co= 9.76   K[Mg/Na]*Q/Co= 3.91

	Ca	Mg	Na	K
Liquid conc mg/L:	380.000	256.000	12500.000	1210.000
Liquid conc meq/L:	19.000	21.053	574.425	30.946
Liquid equiv frac:	.031	.034	.935	
Resin equiv frac:	.185	.082	.732	
Resin conc eq/L:	.371	.164	1.465	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .138944 eq/L

K[Ca/Na]*Q/Co= 43.18   K[Mg/Na]*Q/Co= 17.27

	Ca	Mg	Na	K
Liquid conc mg/L:	440.000	137.000	2310.000	205.000
Liquid conc meq/L:	22.000	11.266	105.678	5.243
Liquid equiv frac:	.158	.081	.761	
Resin equiv frac:	.637	.131	.232	
Resin conc eq/L:	1.275	.261	.464	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

	Ca	Mg	Na
Resin cap eq/L:	.904	.097	-1.001

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	21.513	14.493	3143.563	205.000
Liquid conc meq/L:	1.076	1.192	136.677	5.243
Liquid equiv frac:	.008	.009	.984	

L.02.12

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .651809 eq/L

K[Ca/Na]*Q/Co= 9.21   K[Mg/Na]*Q/Co= 3.68

	Ca	Mg	Na	K
Liquid conc mg/L:	380.000	287.000	13300.000	1210.000
Liquid conc meq/L:	19.000	23.602	609.207	30.946
Liquid equiv frac:	.029	.036	.935	
Resin equiv frac:	.170	.085	.745	
Resin conc eq/L:	.341	.169	1.490	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .142669 eq/L

K[Ca/Na]*Q/Co= 42.06   K[Mg/Na]*Q/Co= 16.82

	Ca	Mg	Na	K
Liquid conc mg/L:	440.000	140.000	2390.000	205.000
Liquid conc meq/L:	22.000	11.513	109.156	5.243
Liquid equiv frac:	.154	.081	.765	
Resin equiv frac:	.630	.132	.238	
Resin conc eq/L:	1.260	.264	.477	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	.919	.094	-1.013

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	20.185	15.245	3229.343	205.000
Liquid conc meq/L:	1.009	1.254	140.406	5.243
Liquid equiv frac:	.007	.009	.984	

L.03.35

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .638454 eq/L

K[Ca/Na]*Q/Co= 9.40   K[Mg/Na]*Q/Co= 3.76

	Ca	Mg	Na	K
Liquid conc mg/L:	360.000	268.000	13200.000	958.000
Liquid conc meq/L:	18.000	22.039	598.414	24.501
Liquid equiv frac:	.028	.035	.937	
Resin equiv frac:	.169	.083	.748	
Resin conc eq/L:	.338	.165	1.497	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .140053 eq/L

K[Ca/Na]*Q/Co= 42.84   K[Mg/Na]*Q/Co= 17.14

	Ca	Mg	Na	K
Liquid conc mg/L:	410.000	137.000	2370.000	205.000
Liquid conc meq/L:	20.500	11.266	108.286	5.243
Liquid equiv frac:	.146	.080	.773	
Resin equiv frac:	.620	.136	.243	
Resin conc eq/L:	1.241	.273	.486	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

	Ca	Mg	Na
Resin cap eq/L:	.903	.107	-1.010

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	19.124	14.237	3172.295	205.000
Liquid conc meq/L:	.956	1.171	137.926	5.243
Liquid equiv frac:	.007	.008	.985	

L.04.11

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .644592 eq/L

K[Ca/Na]*Q/Co= 9.31   K[Mg/Na]*Q/Co= 3.72

	Ca	Mg	Na	K
Liquid conc mg/L:	350.000	317.000	13200.000	1060.000
Liquid conc meq/L:	17.500	26.069	601.023	27.110
Liquid equiv frac:	.027	.040	.932	
Resin equiv frac:	.161	.096	.744	
Resin conc eq/L:	.321	.192	1.487	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .134468 eq/L

K[Ca/Na]*Q/Co= 44.62   K[Mg/Na]*Q/Co= 17.85

	Ca	Mg	Na	K
Liquid conc mg/L:	405.000	125.000	2270.000	205.000
Liquid conc meq/L:	20.250	10.280	103.939	5.243
Liquid equiv frac:	.151	.076	.773	
Resin equiv frac:	.634	.129	.237	
Resin conc eq/L:	1.268	.257	.475	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

	Ca	Mg	Na
Resin cap eq/L:	.946	.066	-1.012

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	16.973	15.373	3044.172	205.000
Liquid conc meq/L:	.849	1.264	132.355	5.243
Liquid equiv frac:	.006	.009	.984	

L.05.54

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.433115 eq/L

K[Ca/Na]*Q/Co= 4.19   K[Mg/Na]*Q/Co= 1.67

	Ca	Mg	Na	K
Liquid conc mg/L:	490.000	366.000	30600.000	1880.000
Liquid conc meq/L:	24.500	30.099	1378.517	48.082
Liquid equiv frac:	.017	.021	.962	
Resin equiv frac:	.063	.031	.905	
Resin conc eq/L:	.127	.062	1.811	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .141185 eq/L

K[Ca/Na]*Q/Co= 42.50   K[Mg/Na]*Q/Co= 17.00

	Ca	Mg	Na	K
Liquid conc mg/L:	420.000	131.000	2390.000	215.000
Liquid conc meq/L:	21.000	10.773	109.412	5.499
Liquid equiv frac:	.149	.076	.775	
Resin equiv frac:	.627	.129	.244	
Resin conc eq/L:	1.254	.257	.488	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

	Ca	Mg	Na
Resin cap eq/L:	1.128	.195	-1.323

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	5.099	3.808	3234.184	215.000
Liquid conc meq/L:	.255	.313	140.617	5.499
Liquid equiv frac:	.002	.002	.996	

L.10.14

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.514845 eq/L

K[Ca/Na]*Q/Co= 3.96   K[Mg/Na]*Q/Co= 1.58

	Ca	Mg	Na	K
Liquid conc mg/L:	330.000	549.000	32100.000	2250.000
Liquid conc meq/L:	16.500	45.148	1453.197	57.545
Liquid equiv frac:	.011	.030	.959	
Resin equiv frac:	.039	.043	.917	
Resin conc eq/L:	.079	.086	1.835	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .140819 eq/L

K[Ca/Na]*Q/Co= 42.61   K[Mg/Na]*Q/Co= 17.04

	Ca	Mg	Na	K
Liquid conc mg/L:	435.000	128.000	2370.000	215.000
Liquid conc meq/L:	21.750	10.526	108.542	5.499
Liquid equiv frac:	.154	.075	.771	
Resin equiv frac:	.637	.123	.240	
Resin conc eq/L:	1.274	.247	.480	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.195	.160	-1.355

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	3.074	5.113	3225.620	215.000
Liquid conc meq/L:	.154	.420	140.244	5.499
Liquid equiv frac:	.001	.003	.996	

L.12.22

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.650783 eq/L

K[Ca/Na]*Q/Co= 3.63   K[Mg/Na]*Q/Co= 1.45

	Ca	Mg	Na	K
Liquid conc mg/L:	304.000	498.000	35300.000	2340.000
Liquid conc meq/L:	15.200	40.954	1594.629	59.847
Liquid equiv frac:	.009	.025	.966	
Resin equiv frac:	.031	.034	.935	
Resin conc eq/L:	.063	.068	1.870	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .138051 eq/L

K[Ca/Na]*Q/Co= 43.46   K[Mg/Na]*Q/Co= 17.38

	Ca	Mg	Na	K
Liquid conc mg/L:	416.000	137.000	2310.000	217.000
Liquid conc meq/L:	20.800	11.266	105.985	5.550
Liquid equiv frac:	.151	.082	.768	
Resin equiv frac:	.627	.136	.238	
Resin conc eq/L:	1.253	.272	.475	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.191	.204	-1.395

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	2.265	3.710	3165.554	217.000
Liquid conc meq/L:	.113	.305	137.633	5.550
Liquid equiv frac:	.001	.002	.997	

L.17.17

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.404646 eq/L

K[Ca/Na]*Q/Co= 4.27   K[Mg/Na]*Q/Co= 1.71

	Ca	Mg	Na	K
Liquid conc mg/L:	288.000	634.000	29200.000	2680.000
Liquid conc meq/L:	14.400	52.138	1338.107	68.542
Liquid equiv frac:	.010	.037	.953	
Resin equiv frac:	.039	.057	.904	
Resin conc eq/L:	.079	.114	1.807	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .135350 eq/L

K[Ca/Na]*Q/Co= 44.33   K[Mg/Na]*Q/Co= 17.73

	Ca	Mg	Na	K
Liquid conc mg/L:	448.000	127.000	2230.000	217.000
Liquid conc meq/L:	22.400	10.444	102.506	5.550
Liquid equiv frac:	.165	.077	.757	
Resin equiv frac:	.652	.122	.226	
Resin conc eq/L:	1.305	.243	.452	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.226	.129	-1.355

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	2.917	6.422	3097.558	217.000
Liquid conc meq/L:	.146	.528	134.676	5.550
Liquid equiv frac:	.001	.004	.995	

L.18.13

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co=1.158213 eq/L

K[Ca/Na]*Q/Co= 5.18 K[Mg/Na]*Q/Co= 2.07

	Ca	Mg	Na	K
Liquid conc mg/L:	560.000	1120.000	22300.000	2680.000
Liquid conc meq/L:	28.000	92.105	1038.107	68.542
Liquid equiv frac:	.024	.080	.896	
Resin equiv frac:	.095	.125	.780	
Resin conc eq/L:	.190	.250	1.560	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .133770 eq/L

K[Ca/Na]*Q/Co= 44.85 K[Mg/Na]*Q/Co= 17.94

	Ca	Mg	Na	K
Liquid conc mg/L:	432.000	97.600	2270.000	213.000
Liquid conc meq/L:	21.600	8.026	104.143	5.448
Liquid equiv frac:	.161	.060	.779	
Resin equiv frac:	.665	.099	.236	
Resin conc eq/L:	1.330	.198	.472	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.141	-.052	-1.089

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	9.031	18.063	3032.149	213.000
Liquid conc meq/L:	.452	1.485	131.833	5.448
Liquid equiv frac:	.003	.011	.986	

L.19.27

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.512209 eq/L

K[Ca/Na]*Q/Co= 3.97   K[Mg/Na]*Q/Co= 1.59

	Ca	Mg	Na	K
Liquid conc mg/L:	816.000	859.000	30900.000	2240.000
Liquid conc meq/L:	40.800	70.641	1400.767	57.289
Liquid equiv frac:	.027	.047	.926	
Resin equiv frac:	.090	.062	.848	
Resin conc eq/L:	.179	.124	1.696	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .136233 eq/L

K[Ca/Na]*Q/Co= 44.04   K[Mg/Na]*Q/Co= 17.62

	Ca	Mg	Na	K
Liquid conc mg/L:	448.000	120.000	2270.000	206.000
Liquid conc meq/L:	22.400	9.868	103.964	5.269
Liquid equiv frac:	.164	.072	.763	
Resin equiv frac:	.655	.115	.230	
Resin conc eq/L:	1.310	.231	.459	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.131	.107	-1.237

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	7.601	8.002	3109.474	206.000
Liquid conc meq/L:	.380	.658	135.195	5.269
Liquid equiv frac:	.003	.005	.992	

L.20.09

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co=1.493589 eq/L

K[Ca/Na]*Q/Co= 4.02 K[Mg/Na]*Q/Co= 1.61

	Ca	Mg	Na	K
Liquid conc mg/L:	256.000	830.000	30900.000	2700.000
Liquid conc meq/L:	12.800	68.257	1412.532	69.054
Liquid equiv frac:	.009	.046	.946	
Resin equiv frac:	.031	.067	.902	
Resin conc eq/L:	.063	.134	1.804	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .130435 eq/L

K[Ca/Na]*Q/Co= 46.00 K[Mg/Na]*Q/Co= 18.40

	Ca	Mg	Na	K
Liquid conc mg/L:	432.000	132.000	2130.000	210.000
Liquid conc meq/L:	21.600	10.855	97.980	5.371
Liquid equiv frac:	.166	.083	.751	
Resin equiv frac:	.650	.131	.219	
Resin conc eq/L:	1.300	.261	.439	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.237	.128	-1.365

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	2.160	7.003	2984.270	210.000
Liquid conc meq/L:	.108	.576	129.751	5.371
Liquid equiv frac:	.001	.004	.995	

L.22.15

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co=1.443358 eq/L

K[Ca/Na]*Q/Co= 4.16 K[Mg/Na]*Q/Co= 1.66

	Ca	Mg	Na	K
Liquid conc mg/L:	310.000	572.000	30100.000	2820.000
Liquid conc meq/L:	15.500	47.039	1380.818	72.123
Liquid equiv frac:	.011	.033	.957	
Resin equiv frac:	.040	.049	.910	
Resin conc eq/L:	.081	.098	1.821	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .136208 eq/L

K[Ca/Na]*Q/Co= 44.05 K[Mg/Na]*Q/Co= 17.62

	Ca	Mg	Na	K
Liquid conc mg/L:	436.000	127.000	2270.000	206.000
Liquid conc meq/L:	21.800	10.444	103.964	5.269
Liquid equiv frac:	.160	.077	.763	
Resin equiv frac:	.645	.124	.231	
Resin conc eq/L:	1.291	.247	.462	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.210	.149	-1.359

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	2.990	5.517	3118.918	206.000
Liquid conc meq/L:	.149	.454	135.605	5.269
Liquid equiv frac:	.001	.003	.996	

L.23.19

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.435829 eq/L

K[Ca/Na]*Q/Co= 4.18   K[Mg/Na]*Q/Co= 1.67

	Ca	Mg	Na	K
Liquid conc mg/L:	512.000	566.000	29800.000	2660.000
Liquid conc meq/L:	25.600	46.546	1363.683	68.031
Liquid equiv frac:	.018	.032	.950	
Resin equiv frac:	.065	.047	.888	
Resin conc eq/L:	.130	.095	1.775	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .137711 eq/L

K[Ca/Na]*Q/Co= 43.57   K[Mg/Na]*Q/Co= 17.43

	Ca	Mg	Na	K
Liquid conc mg/L:	451.000	115.000	2310.000	206.000
Liquid conc meq/L:	22.550	9.457	105.703	5.269
Liquid equiv frac:	.164	.069	.768	
Resin equiv frac:	.657	.110	.233	
Resin conc eq/L:	1.314	.220	.466	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.184	.126	-1.309

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	5.166	5.711	3150.599	206.000
Liquid conc meq/L:	.258	.470	136.983	5.269
Liquid equiv frac:	.002	.003	.995	

L.24.11

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.363559 eq/L

K[Ca/Na]*Q/Co= 4.40   K[Mg/Na]*Q/Co= 1.76

	Ca	Mg	Na	K
Liquid conc mg/L:	352.000	478.000	28700.000	2300.000
Liquid conc meq/L:	17.600	39.309	1306.650	58.824
Liquid equiv frac:	.013	.029	.958	
Resin equiv frac:	.051	.045	.904	
Resin conc eq/L:	.101	.090	1.808	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .134726 eq/L

K[Ca/Na]*Q/Co= 44.53   K[Mg/Na]*Q/Co= 17.81

	Ca	Mg	Na	K
Liquid conc mg/L:	432.000	117.000	2270.000	188.000
Liquid conc meq/L:	21.600	9.622	103.504	4.808
Liquid equiv frac:	.160	.071	.768	
Resin equiv frac:	.652	.116	.232	
Resin conc eq/L:	1.304	.232	.464	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.202	.142	-1.344

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	3.709	5.037	3084.896	188.000
Liquid conc meq/L:	.185	.414	134.126	4.808
Liquid equiv frac:	.001	.003	.996	

L.25.22

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.529883 eq/L

K[Ca/Na]*Q/Co= 3.92   K[Mg/Na]*Q/Co= 1.57

	Ca	Mg	Na	K
Liquid conc mg/L:	800.000	1320.000	30600.000	1990.000
Liquid conc meq/L:	40.000	108.553	1381.330	50.895
Liquid equiv frac:	.026	.071	.903	
Resin equiv frac:	.085	.092	.823	
Resin conc eq/L:	.170	.185	1.645	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .136275 eq/L

K[Ca/Na]*Q/Co= 44.03   K[Mg/Na]*Q/Co= 17.61

	Ca	Mg	Na	K
Liquid conc mg/L:	432.000	129.000	2270.000	210.000
Liquid conc meq/L:	21.600	10.609	104.066	5.371
Liquid equiv frac:	.159	.078	.764	
Resin equiv frac:	.642	.126	.232	
Resin conc eq/L:	1.284	.252	.463	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.114	.068	-1.182

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	7.625	12.582	3101.759	210.000
Liquid conc meq/L:	.381	1.035	134.859	5.371
Liquid equiv frac:	.003	.008	.990	

L.26.14

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co=1.476534 eq/L

K[Ca/Na]*Q/Co= 4.06 K[Mg/Na]*Q/Co= 1.63

	Ca	Mg	Na	K
Liquid conc mg/L:	464.000	605.000	30600.000	2860.000
Liquid conc meq/L:	23.200	49.753	1403.581	73.146
Liquid equiv frac:	.016	.034	.951	
Resin equiv frac:	.057	.049	.895	
Resin conc eq/L:	.113	.097	1.790	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .135120 eq/L

K[Ca/Na]*Q/Co= 44.40 K[Mg/Na]*Q/Co= 17.76

	Ca	Mg	Na	K
Liquid conc mg/L:	448.000	127.000	2230.000	208.000
Liquid conc meq/L:	22.400	10.444	102.276	5.320
Liquid equiv frac:	.166	.077	.757	
Resin equiv frac:	.653	.122	.225	
Resin conc eq/L:	1.306	.244	.451	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.193	.146	-1.339

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	4.258	5.551	3092.370	208.000
Liquid conc meq/L:	.213	.457	134.451	5.320
Liquid equiv frac:	.002	.003	.995	

1.01.01B

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.487000 eq/L

K[Ca/Na]*Q/Co= 4.03   K[Mg/Na]*Q/Co= 1.61

	Ca	Mg	Na	K
Liquid conc mg/L:	620.000	437.760	32660.000	0.000
Liquid conc meq/L:	31.000	36.000	1420.000	0.000
Liquid equiv frac:	.021	.024	.955	
Resin equiv frac:	.073	.034	.892	
Resin conc eq/L:	.147	.068	1.785	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .155200 eq/L

K[Ca/Na]*Q/Co= 38.66   K[Mg/Na]*Q/Co= 15.46

	Ca	Mg	Na	K
Liquid conc mg/L:	480.000	276.032	2495.500	0.000
Liquid conc meq/L:	24.000	22.700	108.500	0.000
Liquid equiv frac:	.155	.146	.699	
Resin equiv frac:	.569	.215	.216	
Resin conc eq/L:	1.138	.431	.431	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	.991	.362	-1.353

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	7.331	5.176	3551.379	0.000
Liquid conc meq/L:	.367	.426	154.408	0.000
Liquid equiv frac:	.002	.003	.995	

1.01.02X

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.462900 eq/L

K[Ca/Na]*Q/Co= 4.10   K[Mg/Na]*Q/Co= 1.64

	Ca	Mg	Na	K
Liquid conc mg/L:	734.000	318.592	32200.000	0.000
Liquid conc meq/L:	36.700	26.200	1400.000	0.000
Liquid equiv frac:	.025	.018	.957	
Resin equiv frac:	.088	.025	.886	
Resin conc eq/L:	.177	.050	1.773	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .116500 eq/L

K[Ca/Na]*Q/Co= 51.50   K[Mg/Na]*Q/Co= 20.60

	Ca	Mg	Na	K
Liquid conc mg/L:	454.000	6.080	2145.900	0.000
Liquid conc meq/L:	22.700	.500	93.300	0.000
Liquid equiv frac:	.195	.004	.801	
Resin equiv frac:	.771	.007	.222	
Resin conc eq/L:	1.542	.014	.444	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.366	-.037	-1.329

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	5.045	2.190	2669.556	0.000
Liquid conc meq/L:	.252	.180	116.068	0.000
Liquid equiv frac:	.002	.002	.996	

1.01.02B

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.408000 eq/L

K[Ca/Na]*Q/Co= 4.26   K[Mg/Na]*Q/Co= 1.70

	Ca	Mg	Na	K
Liquid conc mg/L:	466.000	543.552	30820.000	0.000
Liquid conc meq/L:	23.300	44.700	1340.000	0.000
Liquid equiv frac:	.017	.032	.952	
Resin equiv frac:	.062	.047	.891	
Resin conc eq/L:	.124	.095	1.782	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .152600 eq/L

K[Ca/Na]*Q/Co= 39.32   K[Mg/Na]*Q/Co= 15.73

	Ca	Mg	Na	K
Liquid conc mg/L:	840.000	113.088	2329.900	0.000
Liquid conc meq/L:	42.000	9.300	101.300	0.000
Liquid equiv frac:	.275	.061	.664	
Resin equiv frac:	.757	.067	.176	
Resin conc eq/L:	1.515	.134	.351	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.391	.039	-1.430

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	5.975	6.969	3489.748	0.000
Liquid conc meq/L:	.299	.573	151.728	0.000
Liquid equiv frac:	.002	.004	.994	

1.01.03

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.430000 eq/L

K[Ca/Na]*Q/Co= 4.20   K[Mg/Na]*Q/Co= 1.68

	Ca	Mg	Na	K
Liquid conc mg/L:	480.000	535.040	31326.000	0.000
Liquid conc meq/L:	24.000	44.000	1362.000	0.000
Liquid equiv frac:	.017	.031	.952	
Resin equiv frac:	.062	.045	.893	
Resin conc eq/L:	.124	.091	1.786	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .136400 eq/L

K[Ca/Na]*Q/Co= 43.99   K[Mg/Na]*Q/Co= 17.60

	Ca	Mg	Na	K
Liquid conc mg/L:	536.000	92.416	2346.000	0.000
Liquid conc meq/L:	26.800	7.600	102.000	0.000
Liquid equiv frac:	.196	.056	.748	
Resin equiv frac:	.706	.080	.214	
Resin conc eq/L:	1.412	.160	.427	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.289	.069	-1.358

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	4.767	5.313	3121.669	0.000
Liquid conc meq/L:	.238	.437	135.725	0.000
Liquid equiv frac:	.002	.003	.995	

1.01.04

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .622300 eq/L

K[Ca/Na]*Q/Co= 9.64   K[Mg/Na]*Q/Co= 3.86

	Ca	Mg	Na	K
Liquid conc mg/L:	444.000	280.896	13271.000	0.000
Liquid conc meq/L:	22.200	23.100	577.000	0.000
Liquid equiv frac:	.036	.037	.927	
Resin equiv frac:	.203	.085	.712	
Resin conc eq/L:	.406	.169	1.425	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .138200 eq/L

K[Ca/Na]*Q/Co= 43.42   K[Mg/Na]*Q/Co= 17.37

	Ca	Mg	Na	K
Liquid conc mg/L:	464.000	158.080	2346.000	0.000
Liquid conc meq/L:	23.200	13.000	102.000	0.000
Liquid equiv frac:	.168	.094	.738	
Resin equiv frac:	.638	.143	.218	
Resin conc eq/L:	1.277	.286	.437	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	.871	.117	-.988

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	24.556	15.535	3120.976	0.000
Liquid conc meq/L:	1.228	1.278	135.695	0.000
Liquid equiv frac:	.009	.009	.982	

1.01.05

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .628800 eq/L

K[Ca/Na]*Q/Co= 9.54 K[Mg/Na]*Q/Co= 3.82

	Ca	Mg	Na	K
Liquid conc mg/L:	444.000	274.816	13432.000	0.000
Liquid conc meq/L:	22.200	22.600	584.000	0.000
Liquid equiv frac:	.035	.036	.929	
Resin equiv frac:	.201	.082	.717	
Resin conc eq/L:	.402	.164	1.435	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .143600 eq/L

K[Ca/Na]*Q/Co= 41.78 K[Mg/Na]*Q/Co= 16.71

	Ca	Mg	Na	K
Liquid conc mg/L:	802.000	130.112	2134.400	0.000
Liquid conc meq/L:	40.100	10.700	92.800	0.000
Liquid equiv frac:	.279	.075	.646	
Resin equiv frac:	.755	.081	.164	
Resin conc eq/L:	1.510	.161	.329	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.108	-.002	-1.106

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	25.878	16.017	3242.745	0.000
Liquid conc meq/L:	1.294	1.317	140.989	0.000
Liquid equiv frac:	.009	.009	.982	

1.01.06

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co=1.488000 eq/L

K[Ca/Na]*Q/Co= 4.03 K[Mg/Na]*Q/Co= 1.61

	Ca	Mg	Na	K
Liquid conc mg/L:	480.000	437.760	32844.000	0.000
Liquid conc meq/L:	24.000	36.000	1428.000	0.000
Liquid equiv frac:	.016	.024	.960	
Resin equiv frac:	.058	.035	.907	
Resin conc eq/L:	.116	.070	1.814	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L K[Ca/Na]=3.0 K[Mg/Na]=1.2 Co= .137600 eq/L

K[Ca/Na]*Q/Co= 43.60 K[Mg/Na]*Q/Co= 17.44

	Ca	Mg	Na	K
Liquid conc mg/L:	468.000	148.352	2346.000	0.000
Liquid conc meq/L:	23.400	12.200	102.000	0.000
Liquid equiv frac:	.170	.089	.741	
Resin equiv frac:	.646	.135	.219	
Resin conc eq/L:	1.293	.270	.438	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.177	.200	-1.376

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	4.421	4.032	3152.089	0.000
Liquid conc meq/L:	.221	.332	137.047	0.000
Liquid equiv frac:	.002	.002	.996	

1.01.07

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .530100 eq/L

K[Ca/Na]*Q/Co= 11.32   K[Mg/Na]*Q/Co= 4.53

	Ca	Mg	Na	K
Liquid conc mg/L:	448.000	263.872	11178.000	0.000
Liquid conc meq/L:	22.400	21.700	486.000	0.000
Liquid equiv frac:	.042	.041	.917	
Resin equiv frac:	.246	.095	.658	
Resin conc eq/L:	.493	.191	1.316	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .133200 eq/L

K[Ca/Na]*Q/Co= 45.05   K[Mg/Na]*Q/Co= 18.02

	Ca	Mg	Na	K
Liquid conc mg/L:	832.000	141.056	1840.000	0.000
Liquid conc meq/L:	41.600	11.600	80.000	0.000
Liquid equiv frac:	.312	.087	.601	
Resin equiv frac:	.773	.086	.141	
Resin conc eq/L:	1.546	.172	.282	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

	Ca	Mg	Na
Resin cap eq/L:	1.053	-.019	-1.035

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	32.076	18.893	2990.979	0.000
Liquid conc meq/L:	1.604	1.554	130.043	0.000
Liquid equiv frac:	.012	.012	.976	

1.01.08

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .683800 eq/L

K[Ca/Na]*Q/Co= 8.77   K[Mg/Na]*Q/Co= 3.51

	Ca	Mg	Na	K
Liquid conc mg/L:	360.000	277.248	14789.000	0.000
Liquid conc meq/L:	18.000	22.800	643.000	0.000
Liquid equiv frac:	.026	.033	.940	
Resin equiv frac:	.154	.078	.768	
Resin conc eq/L:	.308	.156	1.536	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .144900 eq/L

K[Ca/Na]*Q/Co= 41.41   K[Mg/Na]*Q/Co= 16.56

	Ca	Mg	Na	K
Liquid conc mg/L:	804.000	136.192	2150.500	0.000
Liquid conc meq/L:	40.200	11.200	93.500	0.000
Liquid equiv frac:	.277	.077	.645	
Resin equiv frac:	.751	.084	.165	
Resin conc eq/L:	1.503	.167	.330	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.194	.011	-1.206

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	17.777	13.691	3286.362	0.000
Liquid conc meq/L:	.889	1.126	142.885	0.000
Liquid equiv frac:	.006	.008	.986	

1.02.01

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co=1.804800 eq/L

K[Ca/Na]*Q/Co= 3.32   K[Mg/Na]*Q/Co= 1.33

	Ca	Mg	Na	K
Liquid conc mg/L:	56.000	24.320	41400.000	0.000
Liquid conc meq/L:	2.800	2.000	1800.000	0.000
Liquid equiv frac:	.002	.001	.997	
Resin equiv frac:	.005	.001	.993	
Resin conc eq/L:	.010	.003	1.987	

EXHAUSTION OF ABOVE REGENERATION

Q=2.00 eq/L   K[Ca/Na]=3.0   K[Mg/Na]=1.2   Co= .128600 eq/L

K[Ca/Na]*Q/Co= 46.66   K[Mg/Na]*Q/Co= 18.66

	Ca	Mg	Na	K
Liquid conc mg/L:	448.000	136.192	2185.000	0.000
Liquid conc meq/L:	22.400	11.200	95.000	0.000
Liquid equiv frac:	.174	.087	.739	
Resin equiv frac:	.658	.132	.210	
Resin conc eq/L:	1.316	.263	.420	

DIFFERENCE BETWEEN REGENERATION AND EXHAUSTION

Resin cap eq/L:	1.306	.260	-1.566

INITIAL EXHAUSTION LEAKAGE CONCENTRATIONS

	Ca	Mg	Na	K
Liquid conc mg/L:	.286	.124	2957.237	0.000
Liquid conc meq/L:	.014	.010	128.576	0.000
Liquid equiv frac:	.000	.000	1.000	

APPENDIX H

Multiple Linear Regression of Laboratory Exhaustion Data

```
******************************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION                  *
******************************************************************************
                                   1.01.01A

Data file name:
Number of observations: 10
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)



                                   1.01.01A


     Variable # 1   Variable # 2
OBS#
   1
         0.00000         .00000
   2
       300.00000         .00000
   3
       600.00000         .00027
   4
      1200.00000         .00040
   5
      1800.00000         .00120
   6
      2400.00000         .00570
   7
      3000.00000         .01200
   8
      3600.00000         .01680
   9
      4200.00000         .01810
  10
      5400.00000         .02200

The following transformation was performed: a*(X^b)+c
  where a =  11.5
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  45.8716
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00000	-150.00000	-12.29225
2	300.00000	.00000	3300.00000	-12.29225
3	600.00000	.00027	6750.00000	-4.39124
✓4	1200.00000	.00040	13650.00000	-3.99820
✓5	1800.00000	.00120	20550.00000	-2.89959
✓6	2400.00000	.00570	27450.00000	-1.34144
✓7	3000.00000	.01200	34350.00000	-.59700
8	3600.00000	.01680	41250.00000	-.26053
9	4200.00000	.01810	48150.00000	-.18600
10	5400.00000	.02200	61950.00000	.00913

Subfile name:	beginning observation	--number of observations
1. 1.01.01A1	1	3
2. 1.01.01A2	4	4
3. 1.01.01A3	8	3

****
POLYNOMIAL REGRESSION ON DATA SET:
1.01.01A
****

--where: Dependent variable = ln(C/C0)
Independent variable = y=Vt-mx

****

POLYNOMIAL REGRESSION on Subfile'1.01.01A2' OF
1.01.01A
****

--where: Dependent variable = ln(C/C0)
Independent variable = y=Vt-mx

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
y=Vt-mx	4	24000.00000			
79350000 M7D.5D					
8907.86170		37.11609			
ln(C/C0)	4	-2.20906	2.34311	1.53072	69.29301

CORRELATION = .991971573633

Selected degree of regression = 1
R-SQUARED = .984007602846

STANDARD ERROR OF ESTIMATE = .237082236732

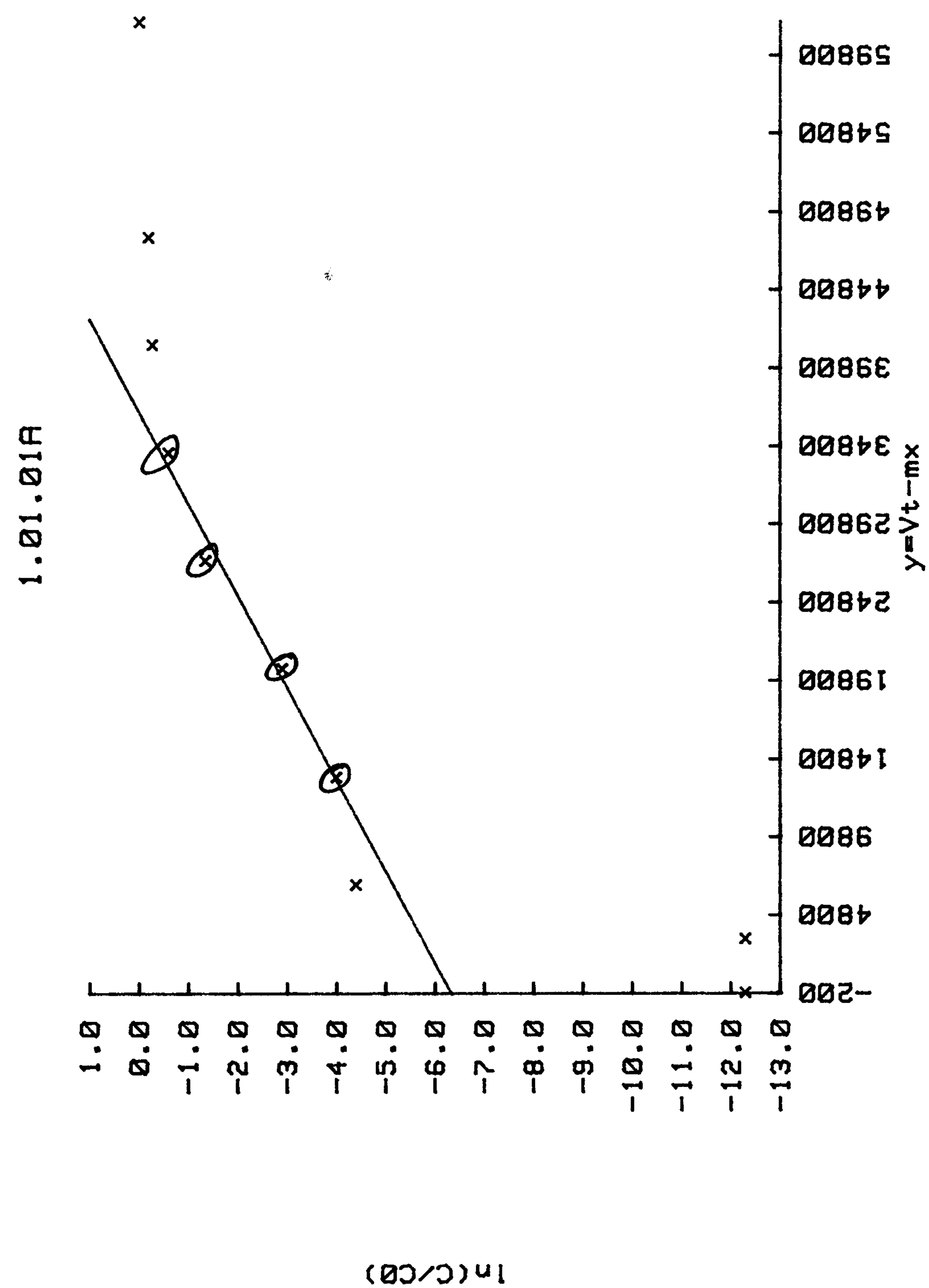
AOV

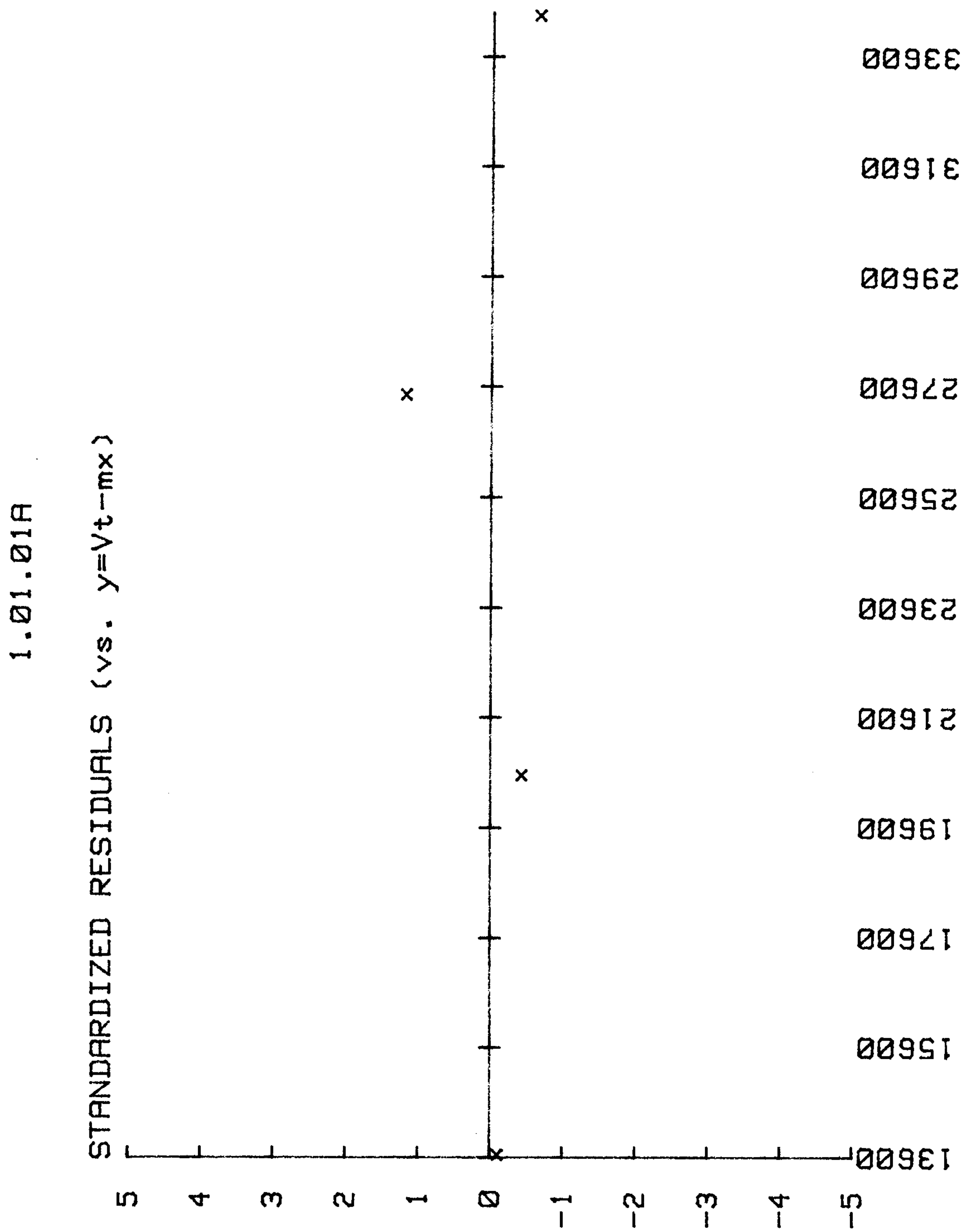
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	3	7.02934		
REGRESSION	1	6.91692	6.91692	123.06
X^1	1	6.91692	6.91692	123.06
RESIDUAL	2	.11242	.05621	

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
'CONSTANT'	-6.30010	-.630009705158E+01	.38737	-16.26
X^1	.00017	.170459953091E-03	.00002	11.09

	COEFFICIENT	95 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-6.30010	-7.95527	-4.64493
X^1	.00017	.00010	.00024

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
4	-3.99820	-3.97332	-.02488	-.10495	
5	-2.89959	-2.79715	-.10244	-.43210	
6	-1.34144	-1.62097	.27953	1.17904	
7	-.59700	-.44480	-.15220	-.64199	


1.01.01A
y=Vt-mx
ln(C/C0)
-200
4800
9800
14800
19800
24800
29800
34800
39800
44800
49800
54800
59800
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0


1.01.01A
STANDARDIZED RESIDUALS (vs. y=Vt-mx)
5
4
3
2
1
0
-1
-2
-3
-4
-5
13600
15600
17600
19600
21600
23600
25600
27600
29600
31600
33600

```
******************************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION                  *
******************************************************************************
                                   1.01.01B

Data file name:
Number of observations: 11
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)


                                   1.01.01B


      Variable # 1   Variable # 2
OBS#
   1
         0.00000         .00020
   2
       600.00000         .00078
   3
      1200.00000         .00220
   4
      1800.00000         .00850
   5
      2400.00000         .01620
   6
      2820.00000         .01980
   7
      3000.00000         .02070
   8
      4080.00000         .01910
   9
      4500.00000         .02220
  10
      5100.00000         .02380
  11
      5700.00000         .02400

The following transformation was performed: a*(X^b)+c
  where a =  11.8
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  41.1523
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).


                                   1.01.01B
```

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00020	-150.00000	-4.79991
2	600.00000	.00078	6930.00000	-3.43894
3	1200.00000	.00220	14010.00000	-2.40202
4	1800.00000	.00850	21090.00000	-1.05041
5	2400.00000	.01620	28170.00000	-.40546
6	2820.00000	.01980	33126.00000	-.20479
7	3000.00000	.02070	35250.00000	-.16034
8	4080.00000	.01910	47994.00000	-.24079
9	4500.00000	.02220	52950.00000	-.09038
10	5100.00000	.02380	60030.00000	-.02079
11	5700.00000	.02400	67110.00000	-.01242

Subfile name:	beginning observation	number of observations
1. 1.01.01B1	1	1
2. 1.01.01B2	2	4
3. 1.01.01B3	6	6

* * * * * The data and related information are stored in 111B:H8 * * * * *

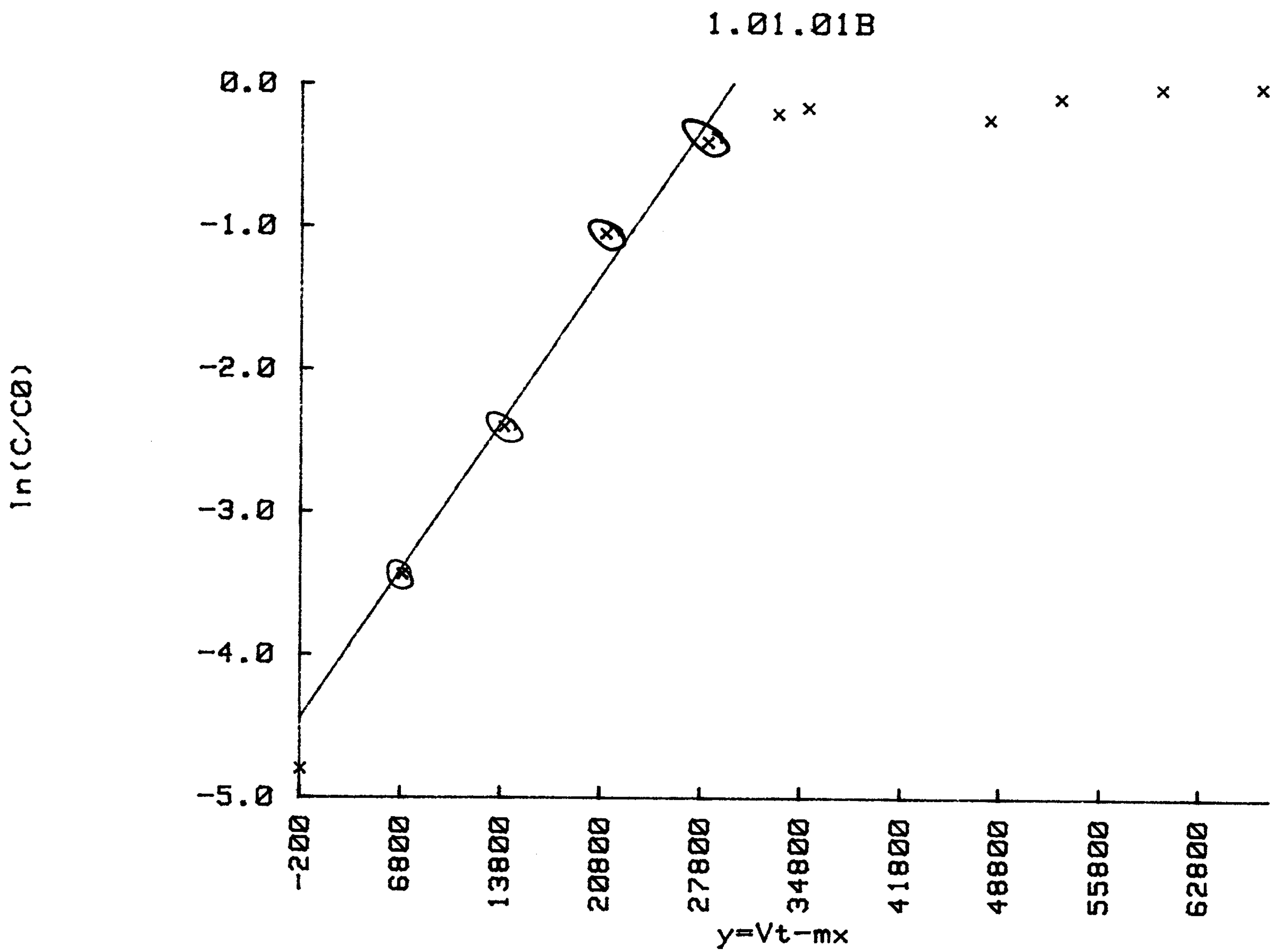
```
********************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                        1.01.01B
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx




********************************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION                    *
********************************************************************************


********************************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION                    *
********************************************************************************
                                        1.01.01B

Data file name: DATA
Number of observations: 11
Number of variables: 4

Variables names:
   1. TIME (s)
   2. C (Ca)
   3. y=Vt-mx
   4. ln(C/C0)

Subfile name     beginning observation--number of observations
 1. 1.01.01B1                      1                       1
 2. 1.01.01B2                      2                       4
 3. 1.01.01B3                      6                       6

********************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.01B2' OF
                                        1.01.01B
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx




                                                        STANDARD     COEFFICIENT
VARIABLE        N          MEAN         VARIANCE       DEVIATION    OF VARIATION
y=Vt-mx         4    17550.00000
83544000 M7D.5D
      9140.24070      52.08114
ln(C/C0)        4       -1.82421         1.85094         1.36049        74.57989

CORRELATION =  .991811233426


Selected degree of regression =  1
R-SQUARED = .9836895228
STANDARD ERROR OF ESTIMATE = .212801567099


                                          AOV
```

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	3	5.55281		
REGRESSION	1	5.46224	5.46224	120.62
X^1	1	5.46224	5.46224	120.62
RESIDUAL	2	.09057	.04528	

	REGRESSION COEFFICIENTS		STANDARD ERROR	
VARIABLE	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	T-VALUE
'CONSTANT'	-4.41507	-.441506963643E+01	.25879	-17.06
X^1	.00015	.147627494460E-03	.00001	10.98

		95 % CONFIDENCE INTERVAL	
	COEFFICIENT	LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-4.41507	-5.52083	-3.30931
X^1	.00015	.00009	.00021

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
2	-3.43894	-3.39201	-.04693	-.22051	
3	-2.40202	-2.34681	-.05521	-.25944	
4	-1.05041	-1.30161	.25120	1.18043	
5	-.40546	-.25640	-.14906	-.70047	


1.Ø1.Ø1B
ln(C/CØ)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-200
6800
13800
20800
27800
34800
41800
48800
55800
62800
y=Vt-mx

```
********************************************************************************
*                      BASIC STATISTICS AND DATA MANIPULATION                  *
********************************************************************************
                                      1.01.02X

Data file name:
Number of observations: 8
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)


                                      1.01.02X


     Variable # 1   Variable # 2
OBS#
   1
         0.00000         .00020
   2
       600.00000         .00020
   3
      1200.00000         .00390
   4
      1800.00000         .00140
   5
      2400.00000         .00570
   6
      3000.00000         .01510
   7
      3720.00000         .01840
   8
      4140.00000         .01880

The following transformation was performed: a*(X^b)+c
  where a =  11.1
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  44.0529
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.02X

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00020	-150.00000	-4.73180
2	600.00000	.00020	6510.00000	-4.73180
✓3	1200.00000	.00390	13170.00000	-1.76139
✓4	1800.00000	.00140	19830.00000	-2.78589
✓5	2400.00000	.00570	26490.00000	-1.38190
✓6	3000.00000	.01510	33150.00000	-.40767
7	3720.00000	.01840	41142.00000	-.21001
8	4140.00000	.01880	45804.00000	-.18851

Subfile name:	beginning observation	number of observations
1. 1.01.02X1	1	2
2. 1.01.02X2	3	4
3. 1.01.02X3	7	2

* * * * * The data and related information are stored in 112X:H8 * * * * *

```
******************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.02X
******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


Observation # 3 Variable # 2 -- correct value =  .00039


                                    1.01.02X
```

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00020	-150.00000	-4.73180
2	600.00000	.00020	6510.00000	-4.73180
✓3	1200.00000	.00039	13170.00000	-1.76139
✓4	1800.00000	.00140	19830.00000	-2.78589
✓5	2400.00000	.00570	26490.00000	-1.38190
✓6	3000.00000	.01510	33150.00000	-.40767
7	3720.00000	.01840	41142.00000	-.21001
8	4140.00000	.01880	45804.00000	-.18851

****
POLYNOMIAL REGRESSION ON DATA SET:
1.01.02X
****

--where: Dependent variable = ln(C/C0)
Independent variable = y=Vt-mx

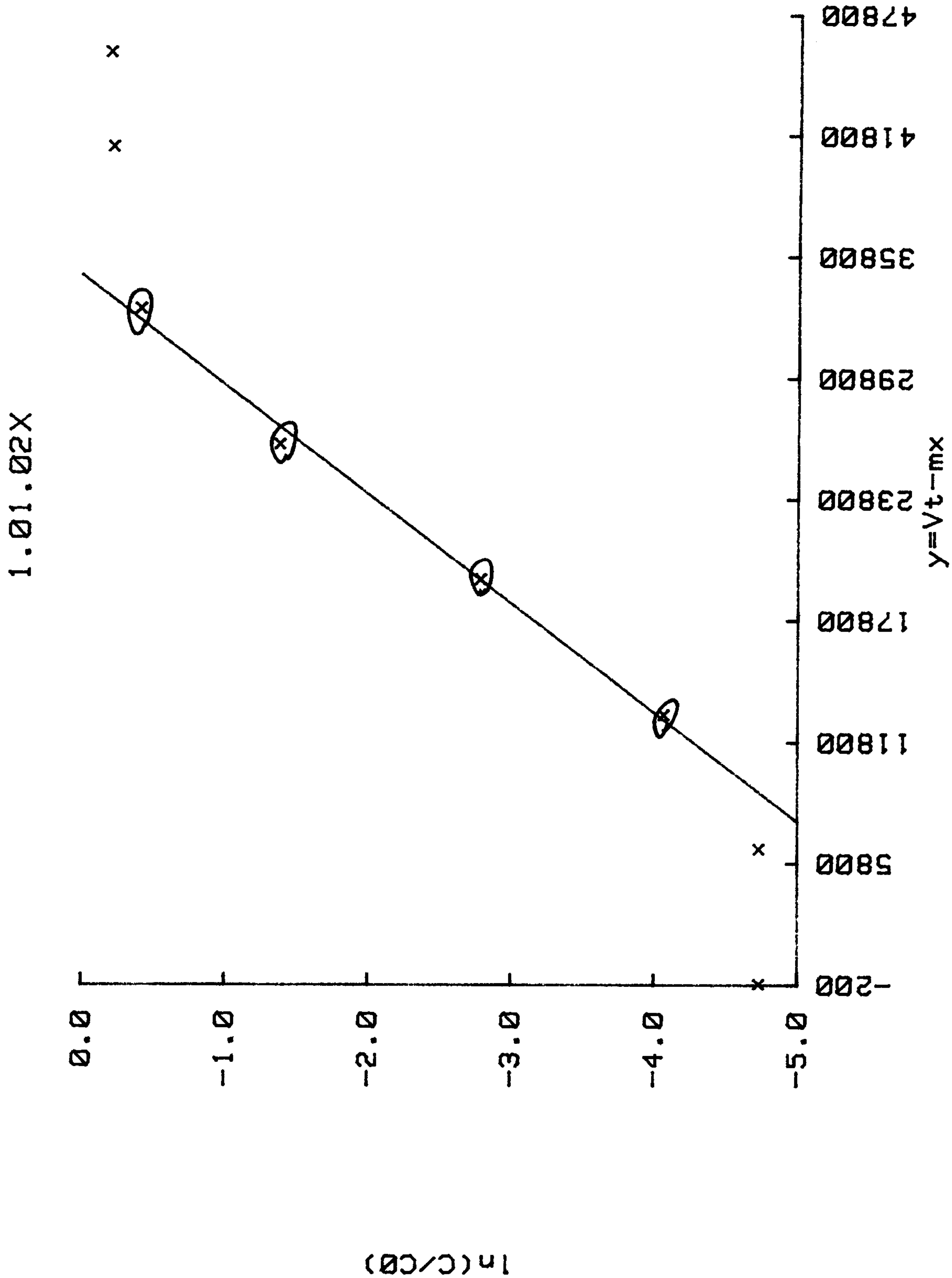
Observation # 3 Variable # 4 -- correct value = -4.063973464

1.01.02X

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00020	-150.00000	-4.73180
2	600.00000	.00020	6510.00000	-4.73180
3	1200.00000	.00039	13170.00000	-4.06397
4	1800.00000	.00140	19830.00000	-2.78589
5	2400.00000	.00570	26490.00000	-1.38190
6	3000.00000	.01510	33150.00000	-.40767
7	3720.00000	.01840	41142.00000	-.21001
8	4140.00000	.01880	45804.00000	-.18851

```
******************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.02X
******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


******************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.02X2' OF
                                    1.01.02X
******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                            STANDARD     COEFFICIENT
VARIABLE        N            MEAN          VARIANCE        DEVIATION    OF VARIATION
y=Vt-mx         4     23160.00000
73926000 M7D.5D
      8598.02303         37.12445
ln(C/C0)        4        -2.15986           2.56432          1.60135        74.14142

CORRELATION =  .997493234792


Selected degree of regression =  1
R-SQUARED = .994992753511
STANDARD ERROR OF ESTIMATE = .138781396736


                                             AOV

SOURCE                  DF      SUM OF SQUARES        MEAN SQUARE       F-VALUE


TOTAL                   3             7.69296
REGRESSION              1             7.65444             7.65444        397.42
 X^1                     1             7.65444             7.65444        397.42
RESIDUAL                2              .03852              .01926


                      REGRESSION COEFFICIENTS         STANDARD ERROR
VARIABLE         STD. FORMAT            E-FORMAT     REG. COEFFICIENT     T-VALUE
'CONSTANT'          -6.46251 -.646250843946E+01                .22671      -28.51
X^1                   .00019  .185779373551E-03                .00001       19.94


                                              95 % CONFIDENCE INTERVAL
                  COEFFICIENT          LOWER LIMIT          UPPER LIMIT
'CONSTANT'           -6.46251             -7.43120             -5.49382
X^1                    .00019               .00015               .00023



 OBS#      OBSERVED Y      PREDICTED Y         RESIDUAL        STAND.RES.      SIGNIF.
```

4	-2.78589	-2.77850	-.00739	-.05324
5	-1.38190	-1.54121	.15931	1.14796
6	-.40767	-.30392	-.10375	-.74756


1.01.02X
y=Vt-mx
ln(C/C0)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-200
5800
11800
17800
23800
29800
35800
41800
47800

```
*******************************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION                   *
*******************************************************************************
                                   1.01.02B

Data file name:
Number of observations: 6
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)

Observation # 4 Variable # 1 -- correct value =  1800
Observation # 4 Variable # 2 -- correct value =  .0256
```

```
                                   1.01.02B
          time, (s)            c (Ca)
      Variable # 1   Variable # 2
OBS#
   1
         0.00000           .00006
   2
       720.00000           .00040
   3
      1200.00000           .00220
   4
      1800.00000           .02560
   5
      2400.00000           .03960
   6
      3000.00000           .41400
                            0
The following transformation was performed: a*(X^b)+c
  where a =  11.18  flow rate ml/sec
        b =  1
        c = -150  - ml BV
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  23.8095  =  1 / Co eq/L
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.02B

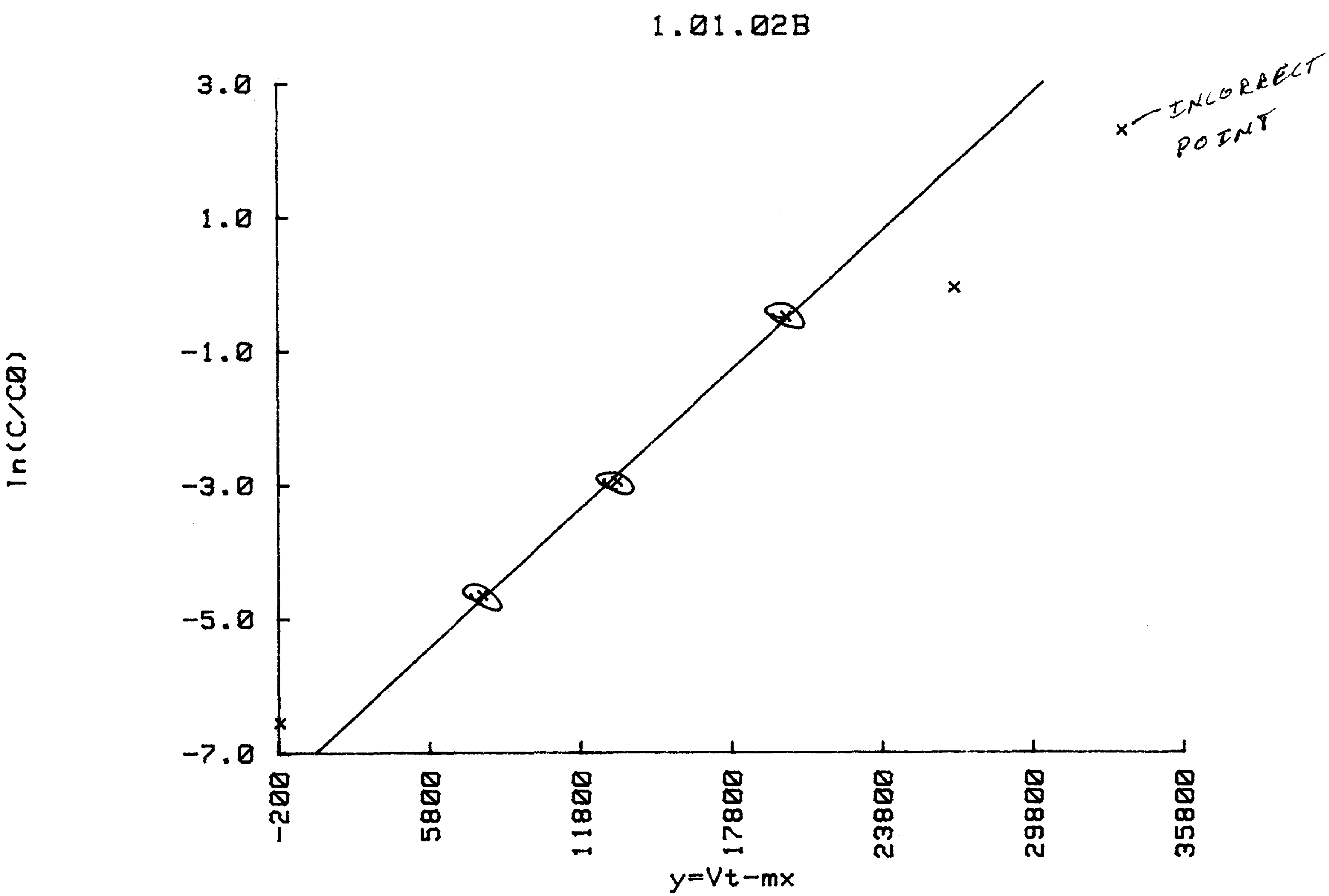
OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00006	-150.00000	-6.55108
2	720.00000	.00040	7899.60000	-4.65396
3	1200.00000	.00220	13266.00000	-2.94921
4	1800.00000	.02560	19974.00000	-.49508
5	2400.00000	.03960	26682.00000	-.05884
6	3000.00000	.41400	33390.00000	2.28820

Subfile name:	beginning observation	number of observations
1. 1.01.02B1	1	1
2. 1.01.02B2	2	3
3. 1.01.02B3	5	2

* * * * * The data and related information are stored in 112B:H8 * * * * *

```
********************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.02B
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


********************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.02B2' OF
                                    1.01.02B
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                         STANDARD      COEFFICIENT
VARIABLE        N          MEAN        VARIANCE         DEVIATION     OF VARIATION
y=Vt-mx         3     13713.20000
36597774.72 M7D.5D
      6049.60947        44.11523
ln(C/C0)        3        -2.69942       4.37088          2.09066          77.44870

CORRELATION =  .99921612946


Selected degree of regression =  1
R-SQUARED = .998432873616
STANDARD ERROR OF ESTIMATE = .117044558566


                                        AOV

SOURCE                  DF      SUM OF SQUARES        MEAN SQUARE        F-VALUE


TOTAL                   2           8.74175
REGRESSION              1           8.72805             8.72805          637.11
 X^1                     1           8.72805             8.72805          637.11
RESIDUAL                1            .01370              .01370


                         REGRESSION COEFFICIENTS         STANDARD ERROR
VARIABLE             STD. FORMAT           E-FORMAT    REG. COEFFICIENT      T-VALUE
'CONSTANT'             -7.43480 -.743480078367E+01             .19941       -37.28
X^1                      .00035  .345315692810E-03             .00001        25.24


                                         95 % CONFIDENCE INTERVAL
                      COEFFICIENT          LOWER LIMIT        UPPER LIMIT
'CONSTANT'              -7.43480            -9.69010           -5.17951
X^1                       .00035              .00019             .00050
```

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
2	-4.65396	-4.70694	.05298	.45268	
3	-2.94921	-2.85384	-.09537	-.81482	
4	-.49508	-.53747	.04239	.36214	


1.01.02B
3.0
1.0
-1.0
-3.0
-5.0
-7.0
ln(C/C0)
-200
5800
11800
17800
23800
29800
35800
y=Vt-mx
INCORRECT POINT

****
* BASIC STATISTICS AND DATA MANIPULATION *
****

1.01.03

Data file name:
Number of observations: 8
Number of variables: 2

Variables names:
1. TIME (s)
2. C (Ca)

1.01.03

OBS#	Variable # 1	Variable # 2
1	0.00000	.00010
2	900.00000	.00040
3	180.00000	.00040
4	3000.00000	.00160
5	6000.00000	.01840
6	7200.00000	.02110
7	8400.00000	.02350
8	9300.00000	.02450

The following transformation was performed: a*(X^b)+c
where a = 5.2
b = 1
c = -150
X is Variable # 1
Transformed data is stored in Variable # 3 (y=Vt-mx).

The following transformation was performed: a*ln(bX)+c
where a = 1
b = 37.3134
c = 0
X is Variable # 2
Transformed data is stored in Variable # 4 (ln(C/C0)).

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-5.59099
2	900.00000	.00040	4530.00000	-4.20469
3	180.00000	.00040	786.00000	-4.20469
4	3000.00000	.00160	15450.00000	-2.81840
5	6000.00000	.01840	31050.00000	-.37605
6	7200.00000	.02110	37290.00000	-.23913
7	8400.00000	.02350	43530.00000	-.13140
8	9300.00000	.02450	48210.00000	-.08973

* * * * * The data and related information are stored in 113:H8 * * * * *

Subfile name:	beginning observation	--number of observations
1. 1.01.031	1	2
2. 1.01.032	3	3
3. 1.01.033	6	3

* * * * * The data and related information are stored in 113:H8 * * * * *

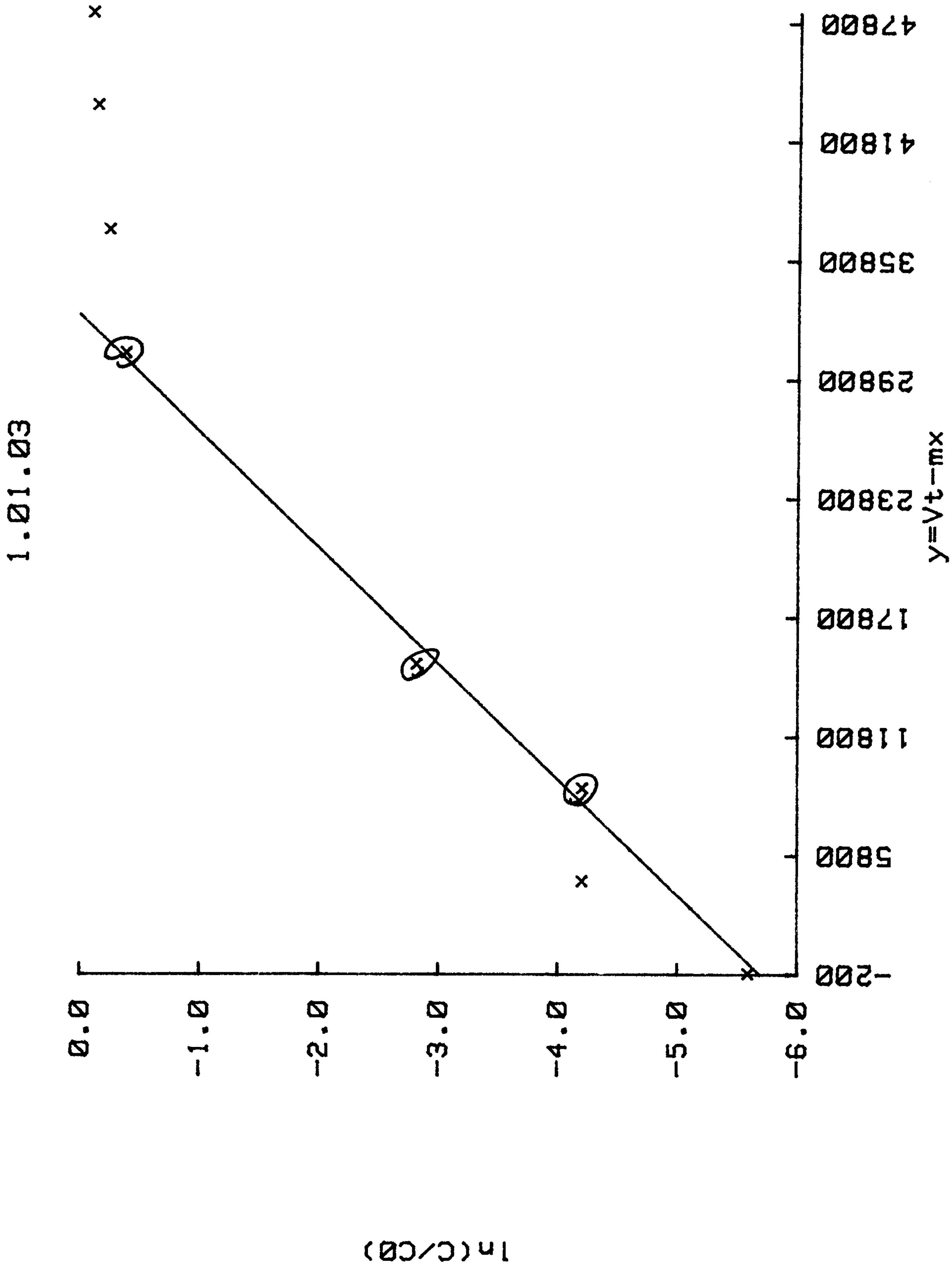
```
*****************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.03
*****************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


Observation # 3 Variable # 1 -- correct value =  1800
Observation # 3 Variable # 3 -- correct value =  9210
```

1.01.03

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-5.59099
2	900.00000	.00040	4530.00000	-4.20469
3	1800.00000	.00040	9210.00000	-4.20469
4	3000.00000	.00160	15450.00000	-2.81840
5	6000.00000	.01840	31050.00000	-.37605
6	7200.00000	.02110	37290.00000	-.23913
7	8400.00000	.02350	43530.00000	-.13140
8	9300.00000	.02450	48210.00000	-.08973

```
*******************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                   1.01.03
*******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


*******************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.032' OF
                                   1.01.03
*******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                            STANDARD    COEFFICIENT
VARIABLE        N          MEAN         VARIANCE           DEVIATION   OF VARIATION
y=Vt-mx         3    18570.00000
126547200 M7D.5D
     11249.31998        60.57792
ln(C/C0)        3       -2.46638         3.75756             1.93844       78.59461

CORRELATION =  .996420199905


Selected degree of regression =  1
R-SQUARED = .992853214994
STANDARD ERROR OF ESTIMATE = .231751939193


                                            AOV

SOURCE                  DF      SUM OF SQUARES        MEAN SQUARE        F-VALUE


TOTAL                   2             7.51512
REGRESSION              1             7.46141             7.46141         138.92
 X^1                     1             7.46141             7.46141         138.92
RESIDUAL                1              .05371              .05371


                        REGRESSION COEFFICIENTS          STANDARD ERROR
VARIABLE           STD. FORMAT            E-FORMAT      REG. COEFFICIENT      T-VALUE
'CONSTANT'          -5.65484 -.565484307776E+01                  .30180       -18.74
X^1                   .00017  .171699595988E-03                  .00001        11.79


                                          95 % CONFIDENCE INTERVAL
                    COEFFICIENT        LOWER LIMIT         UPPER LIMIT
'CONSTANT'             -5.65484           -9.06821            -2.24148
X^1                      .00017             .00001              .00034
```

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
3	-4.20469	-4.07349	-.13120	-.56614	
4	-2.81840	-3.00208	.18369	.79259	
5	-.37605	-.32357	-.05248	-.22646	


1.01.03
y=Vt−mx
ln(C/CØ)
0.Ø
−1.Ø
−2.Ø
−3.Ø
−4.Ø
−5.Ø
−6.Ø
−2ØØ
58ØØ
118ØØ
178ØØ
238ØØ
298ØØ
358ØØ
418ØØ
478ØØ

```
*******************************************************************************
*                  BASIC STATISTICS AND DATA MANIPULATION                     *
*******************************************************************************
                                   1.01.04

Data file name:
Number of observations: 9
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)


                                   1.01.04


     Variable # 1   Variable # 2
OBS#
   1
        0.00000         .00000
   2
      600.00000         .00120
   3
     1200.00000         .00120
   4
     2400.00000         .00180
   5
     3600.00000         .00560
   6
     4800.00000         .01680
   7
     6000.00000         .02010
   8
     7200.00000         .02330
   9
     8400.00000         .02330

The following transformation was performed: a*(X^b)+c
  where a =  5.1
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y+Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  43.1034
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.04

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00000	-150.00000	-12.35449
2	600.00000	.00120	2910.00000	-2.96183
3	1200.00000	.00120	5970.00000	-2.96183
4	2400.00000	.00180	12090.00000	-2.55637
5	3600.00000	.00560	18210.00000	-1.42139
6	4800.00000	.01680	24330.00000	-.32277
7	6000.00000	.02010	30450.00000	-.14343
8	7200.00000	.02330	36570.00000	.00430
9	8400.00000	.02330	42690.00000	.00430

Subfile name:	beginning observation	--number of observations
1. 1.01.041	1	3
2. 1.01.042	4	3
3. 1.01.043	7	3

* * * * * The data and related information are stored in 114:H8 * * * * *

****
POLYNOMIAL REGRESSION ON DATA SET:
1.01.04
****

--where: Dependent variable = ln(C/C0)
Independent variable = y+Vt-mx

****

POLYNOMIAL REGRESSION on Subfile'1.01.042' OF
1.01.04
****

--where: Dependent variable = ln(C/C0)
Independent variable = y+Vt-mx

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
y+Vt-mx	3	18210.00000			
37454400 M7D.5D					
6120.00000		33.60791			
ln(C/C0)	3	-1.43351	1.24734	1.11685	77.90988

CORRELATION = .999955818285

Selected degree of regression = 1
R-SQUARED = .999911638814
STANDARD ERROR OF ESTIMATE = 1.48470047484E-02

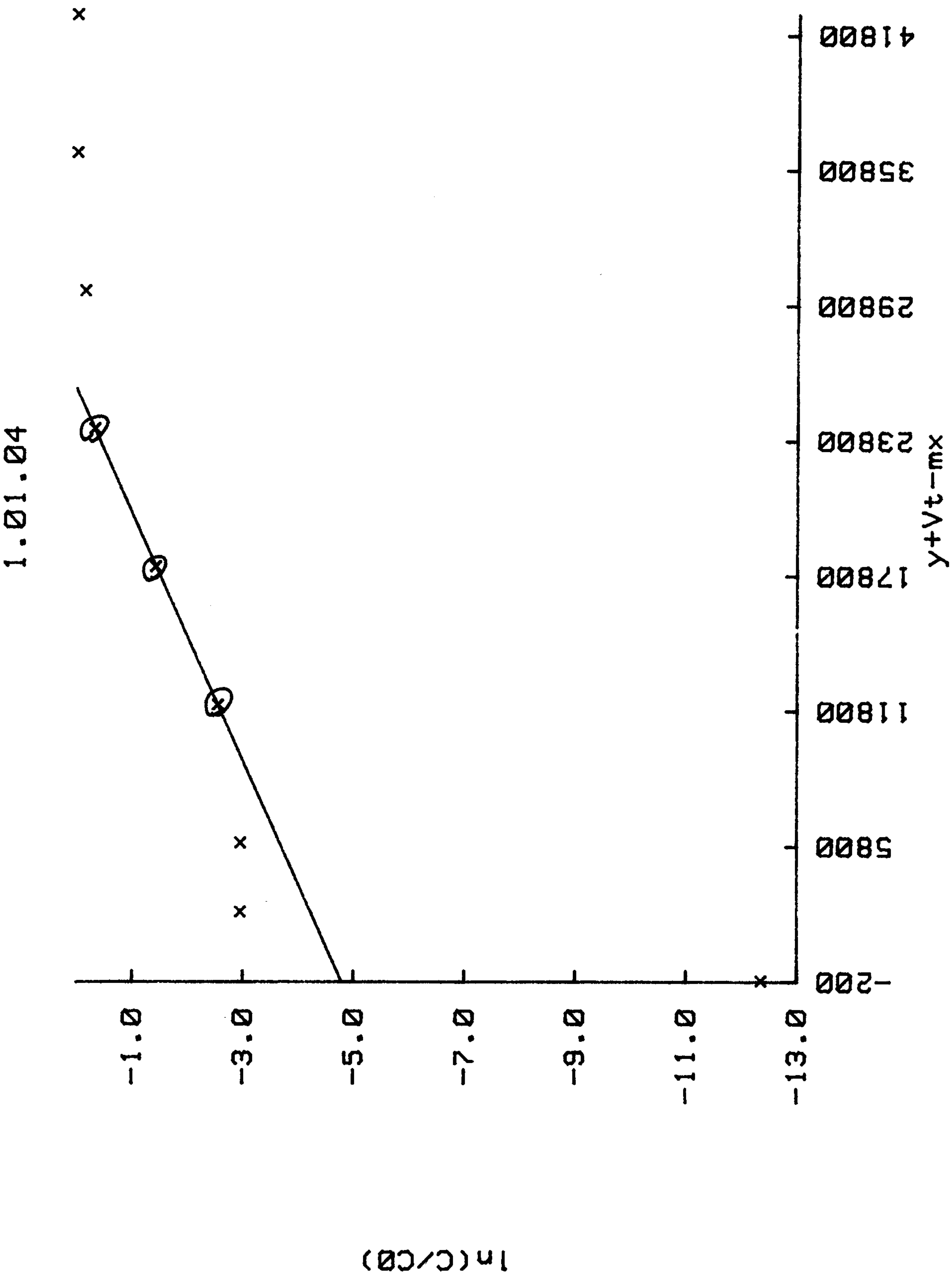
AOV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	2	2.49469		
REGRESSION	1	2.49447	2.49447	11316.19
X^1	1	2.49447	2.49447	11316.19
RESIDUAL	1	.00022	.00022	

VARIABLE	REGRESSION COEFFICIENTS STD. FORMAT	E-FORMAT	STANDARD ERROR REG. COEFFICIENT	T-VALUE
'CONSTANT'	-4.75653	-.475652522828E+01	.03239	-146.84
X^1	.00018	.182483024669E-03	.00000	106.38

	COEFFICIENT	95 % CONFIDENCE INTERVAL LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-4.75653	-5.12289	-4.39016
X^1	.00018	.00016	.00020

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
4	-2.55637	-2.55031	-.00606	-.40825	
5	-1.42139	-1.43351	.01212	.81650	
6	-.32277	-.31671	-.00606	-.40825	


1.01.04
y+Vt-mx
ln(C/C0)
-200
5800
11800
17800
23800
29800
35800
41800
-1.0
-3.0
-5.0
-7.0
-9.0
-11.0
-13.0

```
********************************************************************************
*                        BASIC STATISTICS AND DATA MANIPULATION               *
********************************************************************************
                                          1.01.05

Data file name:
Number of observations: 9
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)


                                          1.01.05


     Variable # 1   Variable # 2
OBS#
   1
        0.00000         .00060
   2
     1020.00000         .00150
   3
     2100.00000         .00780
   4
     3000.00000         .02740
   5
     3900.00000         .03500
   6
     4800.00000         .03920
   7
     5700.00000         .03920
   8
     6600.00000         .03980
   9
     7500.00000         .04100

The following transformation was performed: a*(X^b)+c
  where a =  5.2
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  24.9501
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.05

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00060	-150.00000	-4.20170
2	1020.00000	.00150	5154.00000	-3.28541
3	2100.00000	.00780	10770.00000	-1.63675
4	3000.00000	.02740	15450.00000	-.38033
5	3900.00000	.03500	20130.00000	-.13553
6	4800.00000	.03920	24810.00000	-.02220
7	5700.00000	.03920	29490.00000	-.02220
8	6600.00000	.03980	34170.00000	-.00701
9	7500.00000	.04100	38850.00000	.02269

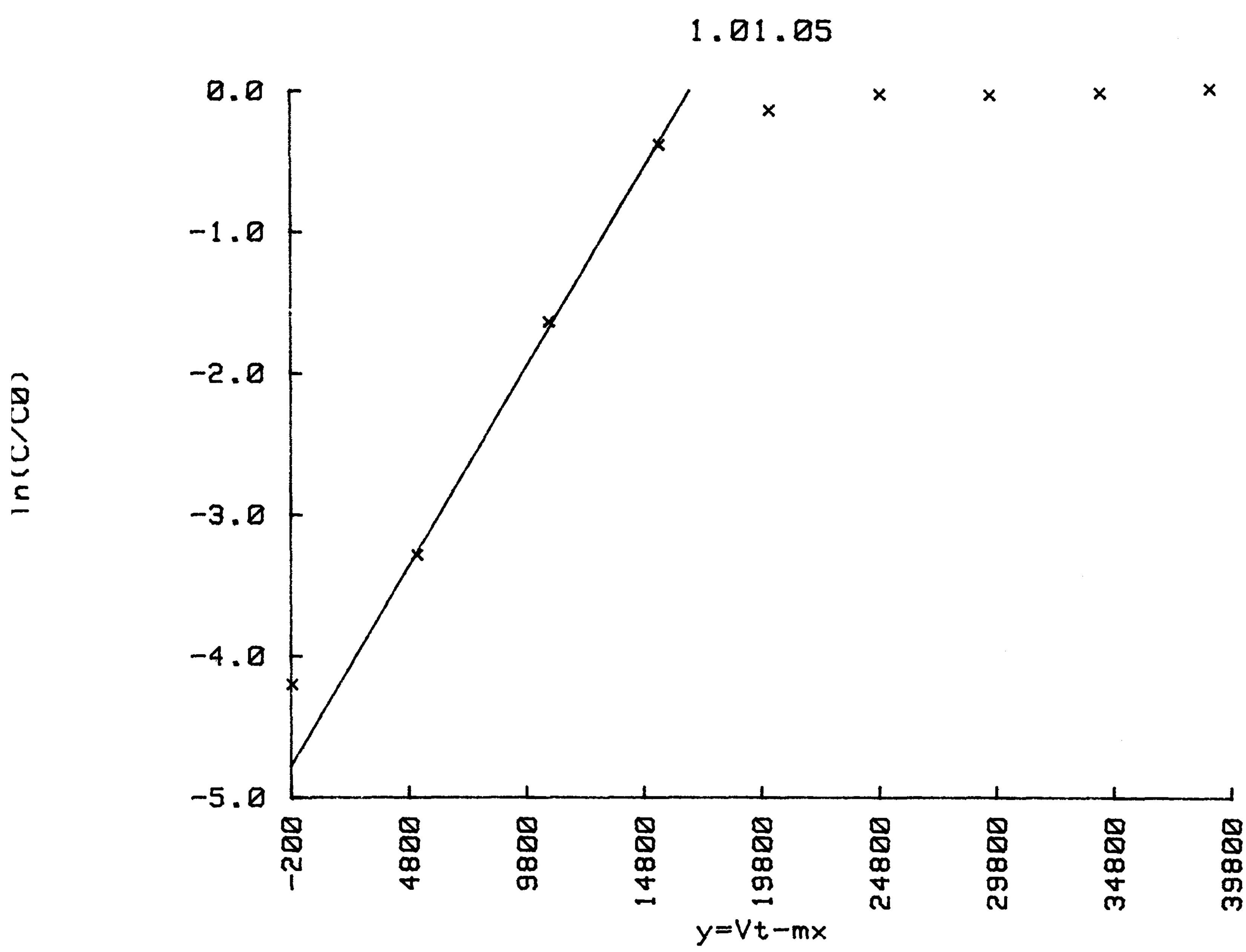
Subfile name:	beginning observation	--number of observations
1. 1.01.051	1	1
2. 1.01.052	2	3
3. 1.01.053	5	5

* * * * * The data and related information are stored in 115:H8 * * * * *

```
*******************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                        1.01.05
*******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


*******************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.052' OF
                                        1.01.05
*******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


*******************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.052' OF
                                        1.01.05
*******************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                             STANDARD      COEFFICIENT
VARIABLE         N              MEAN          VARIANCE       DEVIATION    OF VARIATION
y=Vt-mx          3       10458.00000
26574912 M7D.5D
     5155.08603          49.29323
ln(C/C0)         3          -1.76750           2.12269         1.45695         82.42973

CORRELATION =  .999678518665


Selected degree of regression =  1
R-SQUARED = .99935714082
STANDARD ERROR OF ESTIMATE = 5.22415734831E-02



                                        AOV

SOURCE                 DF      SUM OF SQUARES        MEAN SQUARE        F-VALUE


TOTAL                  2             4.24538
REGRESSION             1             4.24265            4.24265        1554.55
 X^1                    1             4.24265            4.24265        1554.55
RESIDUAL               1              .00273             .00273


                         REGRESSION COEFFICIENTS         STANDARD ERROR
VARIABLE             STD. FORMAT           E-FORMAT    REG. COEFFICIENT      T-VALUE
'CONSTANT'             -4.72222 -.472222067000E+01               .08078       -58.46
X^1                      .00028  .282532081300E-03               .00001        39.43


                                          95 % CONFIDENCE INTERVAL
                      COEFFICIENT        LOWER LIMIT        UPPER LIMIT
```

CONSTANT'	-4.72222	-5.63587	-3.80857
X^1	.00028	.00020	.00036

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
2	-3.28541	-3.26605	-.01936	-.37062	
3	-1.63675	-1.67935	.04260	.81537	
4	-.38033	-.35710	-.02323	-.44475	


1.01.05
ln(C/C0)
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-200
4800
9800
14800
19800
24800
29800
34800
39800
y=Vt-mx

```
********************************************************************************
*                      BASIC STATISTICS AND DATA MANIPULATION                  *
********************************************************************************
                                    1.01.06

Data file name:
Number of observations: 9
Number of variables: 2

Variables names:
   1. TIME (s)
   2. C (Ca)


                                    1.01.06


     Variable # 1   Variable # 2
OBS#
   1
          0.00000          .00010
   2
        660.00000          .00020
   3
       1560.00000          .00240
   4
       2280.00000          .01100
   5
       2760.00000          .01470
   6
       3960.00000          .02180
   7
       4560.00000          .02220
   8
       5160.00000          .02240
   9
       5760.00000          .02440

The following transformation was performed: a*(X^b)+c
  where a =  11
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  42.735
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.06

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-5.45532
2	660.00000	.00020	7110.00000	-4.76217
3	1560.00000	.00240	17010.00000	-2.27727
4	2280.00000	.01100	24930.00000	-.75484
5	2760.00000	.01470	30210.00000	-.46489
6	3960.00000	.02180	43410.00000	-.07083
7	4560.00000	.02220	50010.00000	-.05264
8	5160.00000	.02240	56610.00000	-.04368
9	5760.00000	.02440	63210.00000	.04185

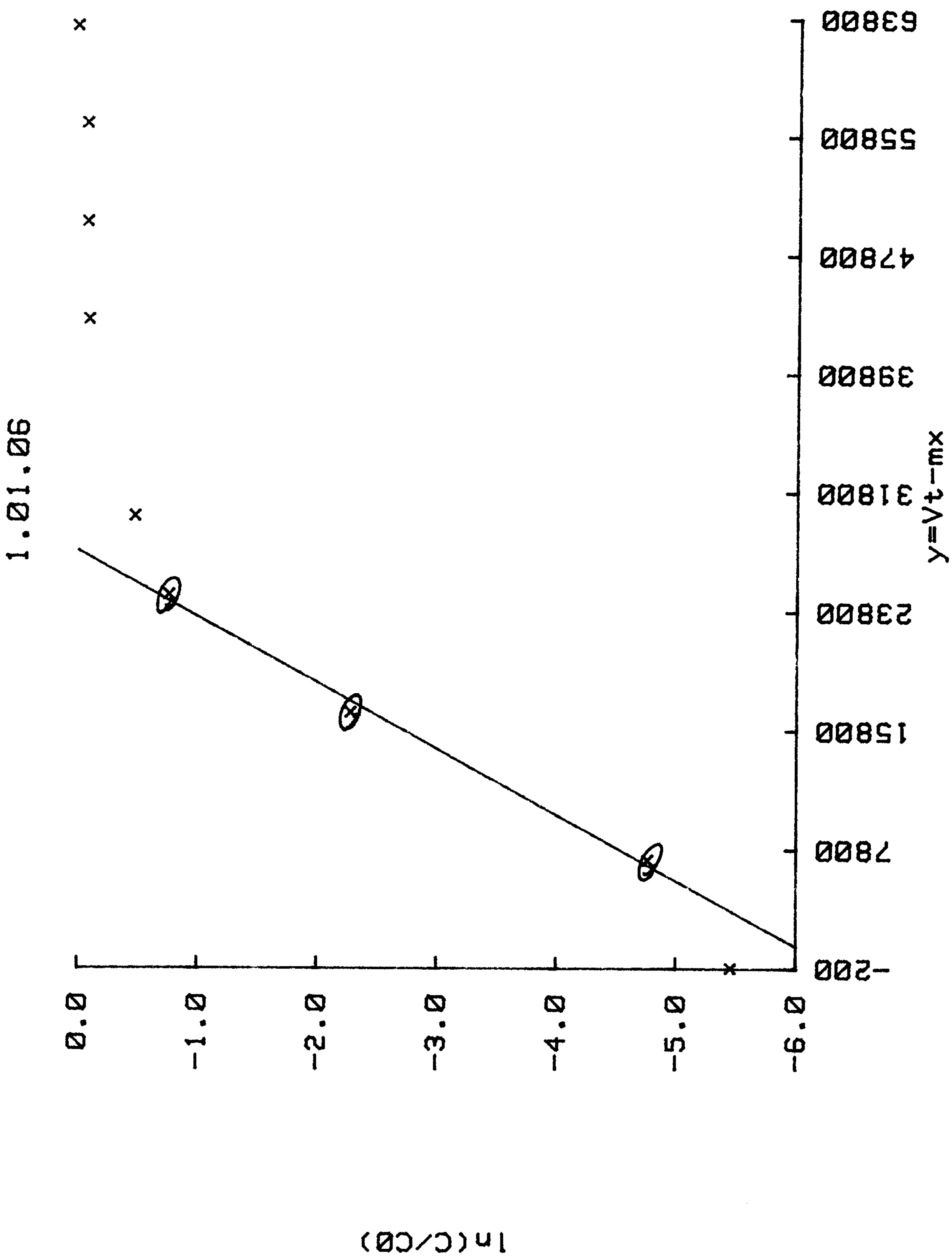
Subfile name:	beginning observation	--number of observations
1. 1.01.061	1	1
2. 1.01.062	2	4
3. 1.01.063	6	4

* * * * * The data and related information are stored in 116:H8 * * * * *

* * * * * The data and related information are stored in 116A:H8 * * * * *

```
******************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.06
******************************************************************************

--where:   Dependent variable = ln(C/C0)
           Independent variable = y=Vt-mx


******************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.062A' OF
                                    1.01.06
******************************************************************************

--where:   Dependent variable = ln(C/C0)
           Independent variable = y=Vt-mx



                                                          STANDARD      COEFFICIENT
VARIABLE        N            MEAN           VARIANCE      DEVIATION    OF VARIATION
y=Vt-mx         3      16350.00000
79714800 M7D.5D
      8928.31451         54.60743
ln(C/C0)        3         -2.59809           4.09188        2.02284        77.85854

CORRELATION =  .99728340432


Selected degree of regression =  1
R-SQUARED = .994574188604
STANDARD ERROR OF ESTIMATE = .210721397323



                                       AOV

SOURCE                 DF      SUM OF SQUARES        MEAN SQUARE       F-VALUE


TOTAL                  2            8.18375
REGRESSION             1            8.13935             8.13935         183.30
 X^1                    1            8.13935             8.13935         183.30
RESIDUAL               1             .04440              .04440

                        REGRESSION COEFFICIENTS         STANDARD ERROR
VARIABLE             STD. FORMAT           E-FORMAT    REG. COEFFICIENT     T-VALUE
'CONSTANT'            -6.29236 -.629236097871E+01              .29875      -21.06
X^1                     .00023  .225948990143E-03              .00002       13.54


                                          95 % CONFIDENCE INTERVAL
                     COEFFICIENT         LOWER LIMIT        UPPER LIMIT
'CONSTANT'             -6.29236            -9.67130           -2.91342
X^1                      .00023           . .00004              .00041
```

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
2	-4.76217	-4.68586	-.07631	-.36214	
3	-2.27727	-2.44897	.17170	.81482	
4	-.75484	-.65945	-.09539	-.45268	


1.01.06
y=Vt-mx
ln(C/C0)
-200
7800
15800
23800
31800
39800
47800
55800
63800
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0

~~ION BALANCE ERROR LISTING~~
Corrected

```
*******************************************************************************
*                  BASIC STATISTICS AND DATA MANIPULATION                     *
*******************************************************************************
```

1.01.07

Data file name: 117:H8
Number of observations: 8
Number of variables: 4

Variables names:
1. TIME (s)
2. C (Ca)
3. y=Vt-mx
4. ln(C/C0)

Subfile name	beginning observation	number of observations
1. 1.01.071	1	2
2. 1.01.072	3	2
3. 1.01.073	5	4

1.01.07

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-6.03068
2	600.00000	.00298	6450.00000	-2.63618
3	1200.00000	.00276	13050.00000	-2.71287
4	1800.00000	.03864	19650.00000	-.07381
5	2340.00000	.03840	25590.00000	-.08004
6	2700.00000	.04000	29550.00000	-.03922
7	3480.00000	.04060	38130.00000	-.02433
8	4200.00000	.04070	46050.00000	-.02187

Observation # 2 Variable # 2 -- correct value = .00398
Observation # 3 Variable # 2 -- correct value = .02276
Observation # 6 Variable # 2 -- correct value = .0464
Observation # 7 Variable # 2 -- correct value = .0407
Observation # 8 Variable # 2 -- correct value = .0406

1.01.07

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-6.03068
2	600.00000	.00398	6450.00000	-2.63618
3	1200.00000	.02276	13050.00000	-2.71287

4				
	1800.00000	.03864	19650.00000	-.07381
5				
	2340.00000	.03840	25590.00000	-.08004
6				
	2700.00000	.04640	29550.00000	-.03922
7				
	3480.00000	.04070	38130.00000	-.02433
8				
	4200.00000	.04060	46050.00000	-.02187

```
The following transformation was performed: a*(X^b)+c
  where a =  11
        b =  1
        c = -150
        X is Variable # 1
        Transformed data is stored in Variable # 3 (y=Vt-mx).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  24.0385
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 4 (ln(C/C0)).
```

1.01.07

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1				
	0.00000	.00010	-150.00000	-6.03068
2				
	600.00000	.00398	6450.00000	-2.34682
3				
	1200.00000	.02276	13050.00000	-.60309
4				
	1800.00000	.03864	19650.00000	-.07381
5				
	2340.00000	.03840	25590.00000	-.08004
6				
	2700.00000	.04640	29550.00000	.10920
7				
	3480.00000	.04070	38130.00000	-.02187
8				
	4200.00000	.04060	46050.00000	-.02433

```
********************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                    1.01.07
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



SUBFILES HAVE BEEN DESTROYED.


Subfile name:    beginning observation--number of observations
```

```
 1. 1.01.01-1                       1                       1
 2. 1.01.07-2                       2                       2
 3. 1.01.07-3                       4                       5

********************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.07-2' OF
                                     1.01.07
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                            STANDARD     COEFFICIENT
VARIABLE        N             MEAN        VARIANCE         DEVIATION    OF VARIATION
y=Vt-mx         2       9750.00000
21780000 M7D.5D
      4666.90476          47.86569
ln(C/C0)        2         -1.47496         1.52028           1.23300        83.59563

CORRELATION =  1.00000000001


Specified maximum degree is too large for computational accuracy!



                                                            STANDARD     COEFFICIENT
VARIABLE        N             MEAN        VARIANCE         DEVIATION    OF VARIATION
y=Vt-mx         2       9750.00000
21780000 M7D.5D
      4666.90476          47.86569
ln(C/C0)        2         -1.47496         1.52028           1.23300        83.59563

CORRELATION =  1.00000000001


Selected degree of regression =  1
R-SQUARED = .999999999342
STANDARD ERROR OF ESTIMATE =
                                             AOV

SOURCE                DF      SUM OF SQUARES       MEAN SQUARE        F-VALUE


TOTAL                 1             1.52028
REGRESSION            1             1.52028            1.52028            0.00
 X^1                   1             1.52028            1.52028            0.00
RESIDUAL              0              .00000


                         REGRESSION COEFFICIENTS          STANDARD ERROR
VARIABLE            STD. FORMAT            E-FORMAT     REG. COEFFICIENT      T-VALUE
'CONSTANT'             -4.05091 -.405090947491E+01               4.86467          -.83
X^1                      .00026  .264200422757E-03                .00000       5754.29


                                            95 % CONFIDENCE INTERVAL
                         COEFFICIENT        LOWER LIMIT         UPPER LIMIT
'CONSTANT'                  -4.05091           -4.05091            -4.05091
X^1                           .00026             .00026              .00026
```

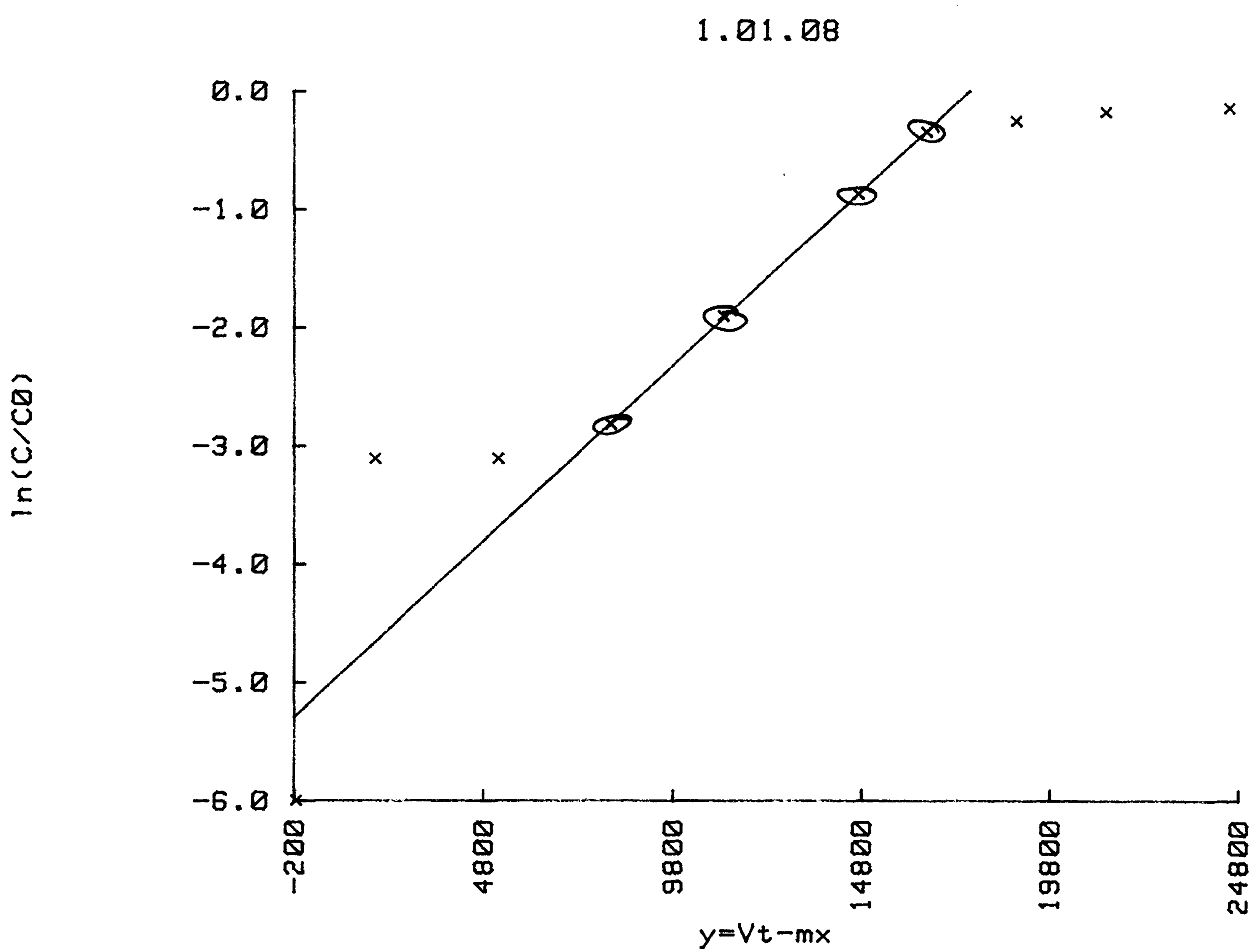
OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00010	-150.00000	-5.99645
2	420.00000	.00180	1929.00000	-3.10608
3	1080.00000	.00180	5196.00000	-3.10608
4	1680.00000	.00240	8166.00000	-2.81840
5	2280.00000	.00600	11136.00000	-1.90211
6	3000.00000	.01690	14700.00000	-.86655
7	3360.00000	.02860	16482.00000	-.34046
8	3840.00000	.03140	18858.00000	-.24706
9	4320.00000	.03400	21234.00000	-.16751
10	4980.00000	.03520	24501.00000	-.13282

Subfile name:	beginning observation	number of observations
1. 1.01.081	1	3
2. 1.01.082	4	4
3. 1.01.083	8	3

* * * * * The data and related information are stored in 118:H8 * * * * *

```
********************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                        1.01.08
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


********************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.01.082' OF
                                        1.01.08
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                              STANDARD     COEFFICIENT
VARIABLE        N           MEAN          VARIANCE           DEVIATION    OF VARIATION
y=Vt-mx         4     12621.00000
13760604 M7D.5D
      3709.52881        29.39172
ln(C/C0)        4        -1.48188          1.21478            1.10217         74.37645

CORRELATION =  .999911536703


Selected degree of regression =  1
R-SQUARED = .999823081271
STANDARD ERROR OF ESTIMATE = 1.79548274845E-02


                                        AOV

SOURCE                DF     SUM OF SQUARES        MEAN SQUARE        F-VALUE


TOTAL                 3           3.64434
REGRESSION            1           3.64369             3.64369         11302.63
 X^1                   1           3.64369             3.64369         11302.63
RESIDUAL              2            .00064              .00032


                      REGRESSION COEFFICIENTS          STANDARD ERROR
VARIABLE          STD. FORMAT           E-FORMAT      REG. COEFFICIENT      T-VALUE
'CONSTANT'          -5.23148 -.523148383303E+01                .03639      -143.75
X^1                   .00030  .297092393153E-03                .00000       106.31


                                         95 % CONFIDENCE INTERVAL
                     COEFFICIENT        LOWER LIMIT        UPPER LIMIT
'CONSTANT'             -5.23148           -5.38699           -5.07598
X^1                      .00030             .00029             .00031
```

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
4	-2.81840	-2.80543	-.01297	-.72247	
5	-1.90211	-1.92306	.02095	1.16707	
6	-.86655	-.86423	-.00233	-.12969	
7	-.34046	-.33481	-.00565	-.31491	



1.01.08
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
ln(C/C0)
-200
4800
9800
14800
19800
24800
y=Vt-mx

BASIC STATISTICS AND DATA MANIPULATION

1.02.01

Data file name:
Number of observations: 14
Number of variables: 2

Variables names:
1. TIME (s)
2. C (Ca)

1.02.01

OBS#	Variable # 1	Variable # 2
1	0.00000	.00002
2	3420.00000	.00002
3	4620.00000	.00030
4	5100.00000	.00090
5	5460.00000	.00138
6	6120.00000	.00134
7	6420.00000	.00720
8	6720.00000	.00924
9	7080.00000	.01184
10	7380.00000	.01480
11	7620.00000	.01560
12	7860.00000	.01840
13	8100.00000	.01820
14	8520.00000	.02180

The following transformation was performed: a*(X^b)+c
where a = 4.98
b = 1
c = -150
X is Variable # 1
Transformed data is stored in Variable # 3 (y=Vt-mx).

The following transformation was performed: a*ln(bX)+c
where a = 1
b = 44.6429
c = 0
X is Variable # 2
Transformed data is stored in Variable # 4 (ln(C/C0)).

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4
1	0.00000	.00002	-150.00000	-7.02108
2	3420.00000	.00002	16881.60000	-7.02108
3	4620.00000	.00030	22857.60000	-4.31303
4	5100.00000	.00090	25248.00000	-3.21442
5	5460.00000	.00138	27040.80000	-2.78698
6	6120.00000	.00134	30327.60000	-2.81639
7	6420.00000	.00720	31821.60000	-1.13498
8	6720.00000	.00924	33315.60000	-.88552
9	7080.00000	.01184	35108.40000	-.63758
10	7380.00000	.01480	36602.40000	-.41443
11	7620.00000	.01560	37797.60000	-.36179
12	7860.00000	.01840	38992.80000	-.19671
13	8100.00000	.01820	40188.00000	-.20764
14	8520.00000	.02180	42279.60000	-.02715

* * * * * The data and related information are stored in 121:H8 * * * * *

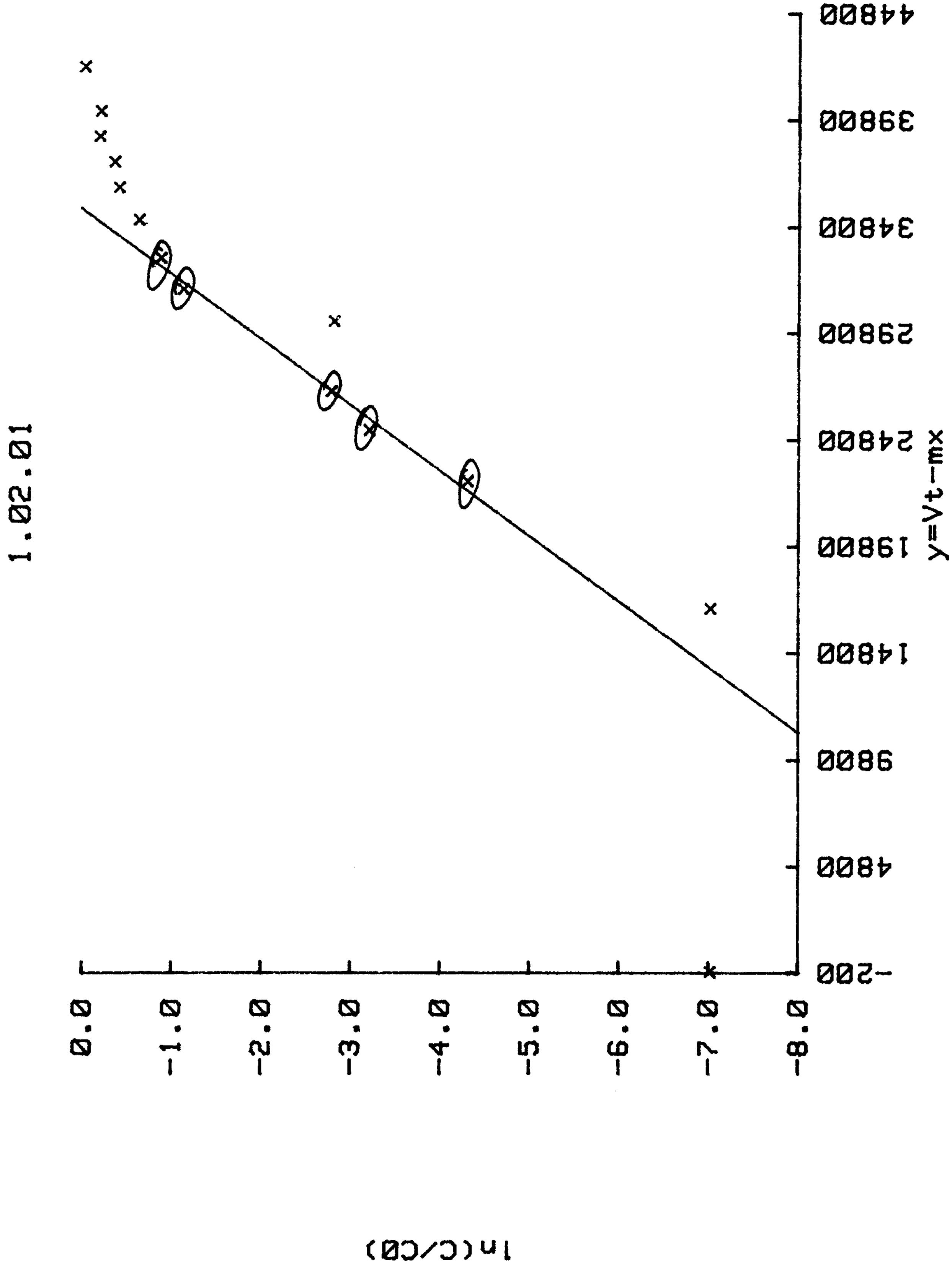
```
********************************************************************************
POLYNOMIAL REGRESSION ON DATA SET:
                                     1.02.01
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx


Observation # 6 has been deleted, 13 observations remain.


Subfile name:     beginning observation--number of observations
 1. 1.02.011A                         1                        2
 2. 1.02.012A                         3                        5
 3. 1.02.013A                         8                        6



* * * * * The data and related information are stored in 121A:H8 * * * * *



********************************************************************************

POLYNOMIAL REGRESSION on Subfile'1.02.012A' OF
                                     1.02.01
********************************************************************************

--where:  Dependent variable = ln(C/C0)
          Independent variable = y=Vt-mx



                                                             STANDARD     COEFFICIENT
VARIABLE         N              MEAN         VARIANCE       DEVIATION    OF VARIATION
y=Vt-mx          5       28056.72000
19445497.63 M7D.5D
      4409.70494         15.71711
ln(C/C0)         5          -2.46699          2.08606         1.44432        58.54589

CORRELATION =  .995201753056


Selected degree of regression =  1
R-SQUARED = .990426529857
STANDARD ERROR OF ESTIMATE = .163180047628


                                      AOV

SOURCE                DF      SUM OF SQUARES        MEAN SQUARE        F-VALUE


TOTAL                 4            8.34422
REGRESSION            1            8.26434            8.26434           310.37
```

X^1	1	8.26434	8.26434	310.37
RESIDUAL	3	.07988	.02663	

	REGRESSION COEFFICIENTS		STANDARD ERROR	
VARIABLE	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	T-VALUE
'CONSTANT'	-11.61236	-.116123598601E+02	.52422	-22.15
X^1	.00033	.325960214856E-03	.00002	17.62

		95 % CONFIDENCE INTERVAL	
	COEFFICIENT	LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-11.61236	-13.27934	-9.94538
X^1	.00033	.00027	.00038

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
3	-4.31303	-4.16169	-.15134	-.92745	
4	-3.21442	-3.38252	.16810	1.03012	
5	-2.78698	-2.79813	.01116	.06838	
6	-1.13498	-1.23978	.10481	.64227	
7	-.88552	-.75280	-.13272	-.81332	


1.02.01
y=Vt-mx
ln(C/C0)
-200
4800
9800
14800
19800
24800
29800
34800
39800
44800
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0

ln k1s vs ln V fixed

Observation # 9 has been deleted, 8 observations remain.

9/26/83 QWK

****
*   BASIC STATISTICS AND DATA MANIPULATION   *
****

K1S CORRELATION

Data file name: KLS:H8
Number of observations: 9
Number of variables: 9

Variables names:
1. K1S (1/s)
2. V (ml/s)
3. T (K)
4. ln(K1S)
5. ln(V)
6. ln(T)
7. V^2
8. T^2
9. T*V

Subfiles: NONE

Observation # 9 Variable # 1 = .0671 has been inserted.
Observation # 9 Variable # 2 = 11 has been inserted.
Observation # 9 Variable # 3 = 290.15 has been inserted.
Observation # 9 Variable # 4 = -9999999.99999 has been inserted.
Observation # 9 Variable # 5 = -9999999.99999 has been inserted.
Observation # 9 Variable # 6 = -9999999.99999 has been inserted.
Observation # 9 Variable # 7 = -9999999.99999 has been inserted.
Observation # 9 Variable # 8 = -9999999.99999 has been inserted.
Observation # 9 Variable # 9 = -9999999.99999 has been inserted.

K1S CORRELATION

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4	Variable # 5	Variable # 6	Variable # 7	Variable # 8	Variable # 9
1	.12190	11.50000	290.15000	-2.10455	2.44235	5.67040	132.25000	84187.02250	3336.72500
2	.08160	11.80000	288.05000	-2.50593	2.46810	5.66313	139.24000	82972.80250	3398.99000
3	.12130	11.10000	307.15000	-2.10949	2.40695	5.72734	123.21000	94341.12250	3409.36500
4	.14390	11.18000	307.15000	1.93864	2.41413	5.72734	124.99240	94341.12250	3433.93700
5	.04840	5.20000	289.15000	-3.02826	1.64866	5.66695	27.04000	83607.72250	1503.58000
6	.038[illegible]	[illegible]0000	307.85000	-3.26231	1.62[illegible]24	5.72[illegible]	[illegible]6.01000	94771.6225[illegible]	1570.03500
7									

```
          .03870        5.20000      308.05000        -3.25192        1.64866
            5.73026       27.04000    94894.80250     1601.86000
 8
          .11640       11.00000      306.35000        -2.15072        2.39790
            5.72473      121.00000    93850.32250     3369.85000
 9
          .06710       11.00000      290.15000 -9999999.99999 -9999999.99999
     -9999999.99999 -9999999.99999 -9999999.99999 -9999999.99999
10
          .04190        4.95000      287.65000        -3.17247        1.59939
            5.66174       24.50250    82742.52250     1423.86750
```

```
The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  1
        c =  0
        X is Variable # 1
        Transformed data is stored in Variable # 4 (ln(K1S)).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  1
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 5 (ln(V)).


The following transformation was performed: a*(X^b)+c
  where a =  1
        b =  2
        c =  0
        X is Variable # 2
        Transformed data is stored in Variable # 7 (V^2).


The following transformation was performed: a*ln(bX)+c
  where a =  1
        b =  1
        c =  0
        X is Variable # 3
        Transformed data is stored in Variable # 6 (ln(T)).


The following transformation was performed: a*(X^b)+c
  where a =  1
        b =  2
        c =  0
        X is Variable # 3
        Transformed data is stored in Variable # 8 (T^2).


The following transformation was performed: a*(X^b)*(Y^c)
  where a =  1
        b =  1
        c =  1
        X is Variable # 2
        Y is Variable # 3
        Transformed data is stored in Variable # 9 (T*V).
```

OBS#	Variable # 1	Variable # 2	Variable # 3	Variable # 4	Variable # 5	Variable # 6	Variable # 7	Variable # 8	Variable # 9
1	.12190	11.50000	290.15000	-2.10455	2.44235	5.67040	132.25000	84187.02250	3336.72500
2	.08160	11.80000	288.05000	-2.50593	2.46810	5.66313	139.24000	82972.80250	3398.99000
3	.12130	11.10000	307.15000	-2.10949	2.40695	5.72734	123.21000	94341.12250	3409.36500
4	.14390	11.18000	307.15000	-1.93864	2.41413	5.72734	124.99240	94341.12250	3433.93700
5	.04840	5.20000	289.15000	-3.02826		5.66695	27.04000	83607.72250	1503.58000
6	.03830	5.10000	307.85000	-3.26231	1.62924	5.72961	26.01000	94771.62250	1570.03500
7	.03870	5.20000	308.05000	-3.25192	1.64866	5.73026	27.04000	94894.80250	1601.86000
8	.11640	11.00000	306.35000	-2.15072	2.39790	5.72473	121.00000	93850.32250	3369.85000
9	.06710	11.00000	290.15000	-2.70157	2.39790	5.67040	121.00000	84187.02250	3191.65000
10	.04190	4.95000	287.65000	-3.17247	1.59939	5.66174	24.50250	82742.52250	1423.86750

****

MANUAL REGRESSION ON
K1S CORRELATION

****

Dependent variable:ln(K1S)
Independent variable(s) = V (ml/s)
T (K)
ln(V)
ln(T)
V^2
T^2
T*V
Tolerance = .001

CORRELATION MATRIX

	V (ml/s)	T (K)	ln(V)	ln(T)	V^2	T^2
V (ml/s)	1.0000000	-.0289987	.9996531	-.0273452	.9995419	-.0306522
T (K)		1.0000000	-.0147433	.9999959	-.0448146	.9999960
ln(V)			1.0000000	.0130484	.9984107	-.0164377
ln(T)				1.0000000	-.0432080	.9999837
V^2					1.0000000	-.0464215
T^2						1.0000000

	T*V	ln(K1S)
V (ml/s)	.9957717	.8994133
T (K)	.0574063	.1508101
ln(V)	.9968831	.9020834
ln(T)	.0590616	.1524846
V^2	.9936062	.8952277
T^2	.0557492	.1491285
T*V	1.0000000	.9202318
ln(K1S)		1.0000000

****

#--VARIABLE	F TO ENTER	PART CORR	TOL	F TO DELETE	REGRESSION COEFFICIENTS STD.FORMAT	E-FORMAT	STD ERROR
2.V (ml/s)	33.87	.899	1.000				
3.T (K)	.19	.151	1.000				
5.ln(V)	34.95	.902	1.000				
6.ln(T)	.19	.152	1.000				
7.V^2	32.29	.895	1.000				
8.T^2	.18	.149	1.000				
9.T*V	44.23	.920	1.000				

****

STEP NUMBER 1
VARIABLE'ln(V)' ADDED
R-SQUARED = .81375437648

AOV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	9	2.51415		
REGRESSION	1	2.04590	2.04590	34.95
RESIDUAL	8	.46825	.05853	

STANDARD ERROR = .241932279574

#--VARIABLE	F TO ENTER	PART CORR	TOL	F TO DELETE	REGRESSION COEFFICIENTS STD.FORMAT	E-FORMAT	STD ERROR
Variable'V (ml/s)'does not exceed tolerance.							
3.T (K)	1.18	.380	1.000				
5.ln(V)				34.95	1.16693	.116692966088E+01	.1974
6.ln(T)	1.19	.381	1.000				
7.V^2	.37	.223	.003				
8.T^2	1.18	.380	1.000				
9.T*V	4.27	.616	.006				

Constant = -5.07935119613

****

STEP NUMBER 2
VARIABLE'ln(V)' DELETED
R-SQUARED = -.00000000001

#--VARIABLE	F TO ENTER	PART CORR	TOL	F TO DELETE	REGRESSION COEFFICIENTS STD.FORMAT	E-FORMAT	STD ERROR
2.V (ml/s)	33.87	.899	1.000				
3.T (K)	.19	.151	1.000				
5.ln(V)	34.95	.902	1.000				
6.ln(T)	.19	.152	1.000				
7.V^2	32.29	.895	1.000				
8.T^2	.18	.149	1.000				
9.T*V	44.23	.920	1.000				

Constant = -2.62258453454

****

STEP NUMBER 3
VARIABLE'V (ml/s)' ADDED
R-SQUARED = .80894419899

AOV

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	9	2.51415		
REGRESSION	1	2.03381	2.03381	33.87
RESIDUAL	8	.48034	.06004	

STANDARD ERROR = .245036563847

#--VARIABLE	F TO ENTER	PART CORR	TOL	F TO DELETE	REGRESSION COEFFICIENTS STD.FORMAT	E-FORMAT	STD ERROR
2.V (ml/s)				33.87	.14921	.149205417475E+00	.0256
3.T (K)	1.37	.405	.999				
Variable'ln(V)'does not exceed tolerance.							
6.ln(T)	1.38	.405	.999				
Variable'V^2'does not exceed tolerance.							
8.T^2	1.37	.404	.999				
9.T*V	4.22	.613	.008				

Constant = -3.93603982457
****
STEP NUMBER 4
VARIABLE'V (ml/s)' DELETED
R-SQUARED = -.00000000001

#--VARIABLE	F TO ENTER	PART CORR	TOL	F TO DELETE	REGRESSION COEFFICIENTS STD.FORMAT	E-FORMAT	STD ERROR
2.V (ml/s)	33.87	.899	1.000				
3.T (K)	.19	.151	1.000				
5.ln(V)	34.95	.902	1.000				
6.ln(T)	.19	.152	1.000				
7.V^2	32.29	.895	1.000				
8.T^2	.18	.149	1.000				
9.T*V	44.23	.920	1.000				

Constant = -2.62258453454
****
POLYNOMIAL REGRESSION ON DATA SET:
K1S CORRELATION
****

--where: Dependent variable = ln(K1S)
Independent variable = ln(V)

VARIABLE	N	MEAN	VARIANCE	STANDARD DEVIATION	COEFFICI. OF VARIATION
ln(V)	10	2.10533	.16694	.40858	19.40695
ln(K1S)	10	-2.62258	.27935	.52854	20.15325

CORRELATION = .902083353385

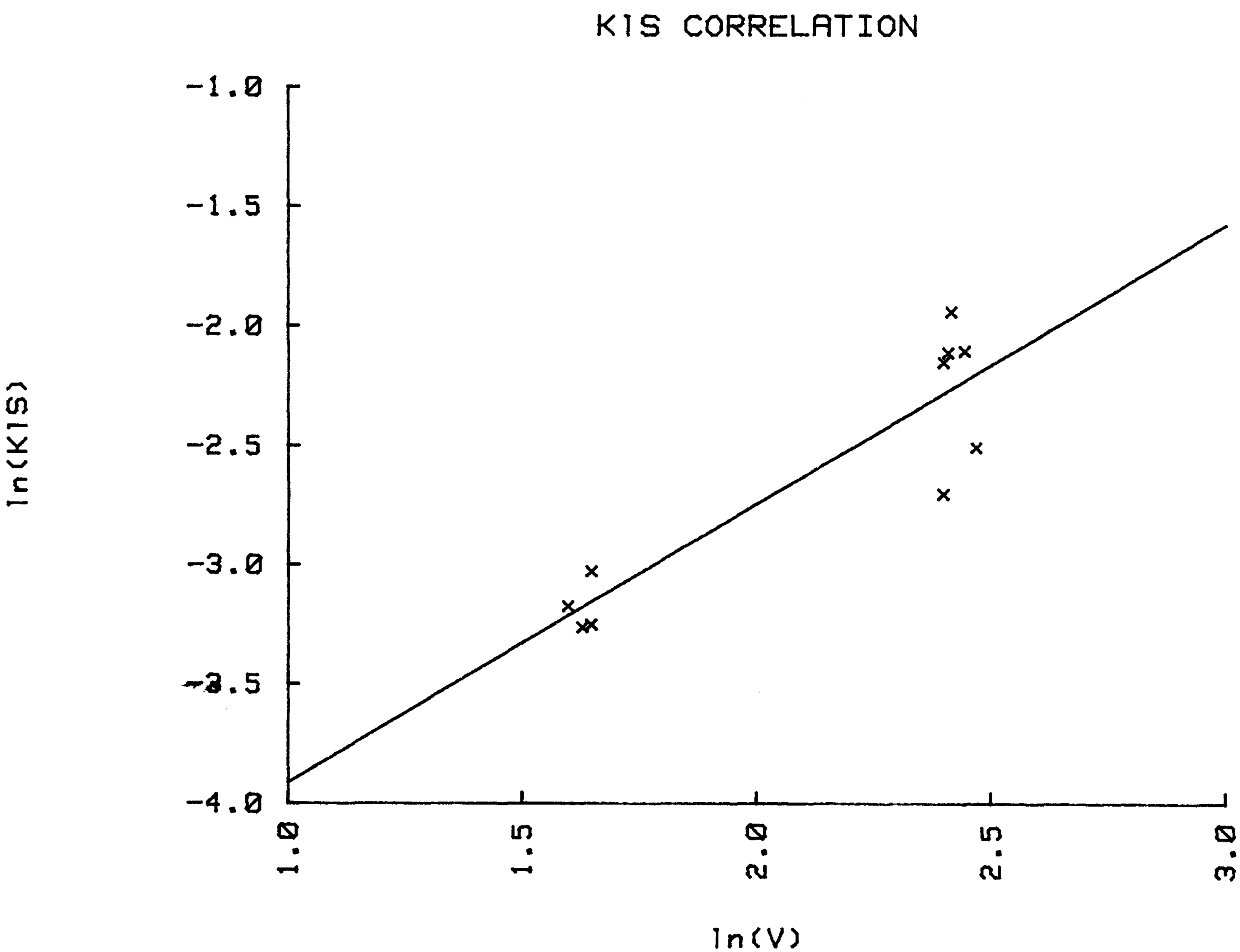
Selected degree of regression = 1
R-SQUARED = .813754377028
STANDARD ERROR OF ESTIMATE = .241932279218

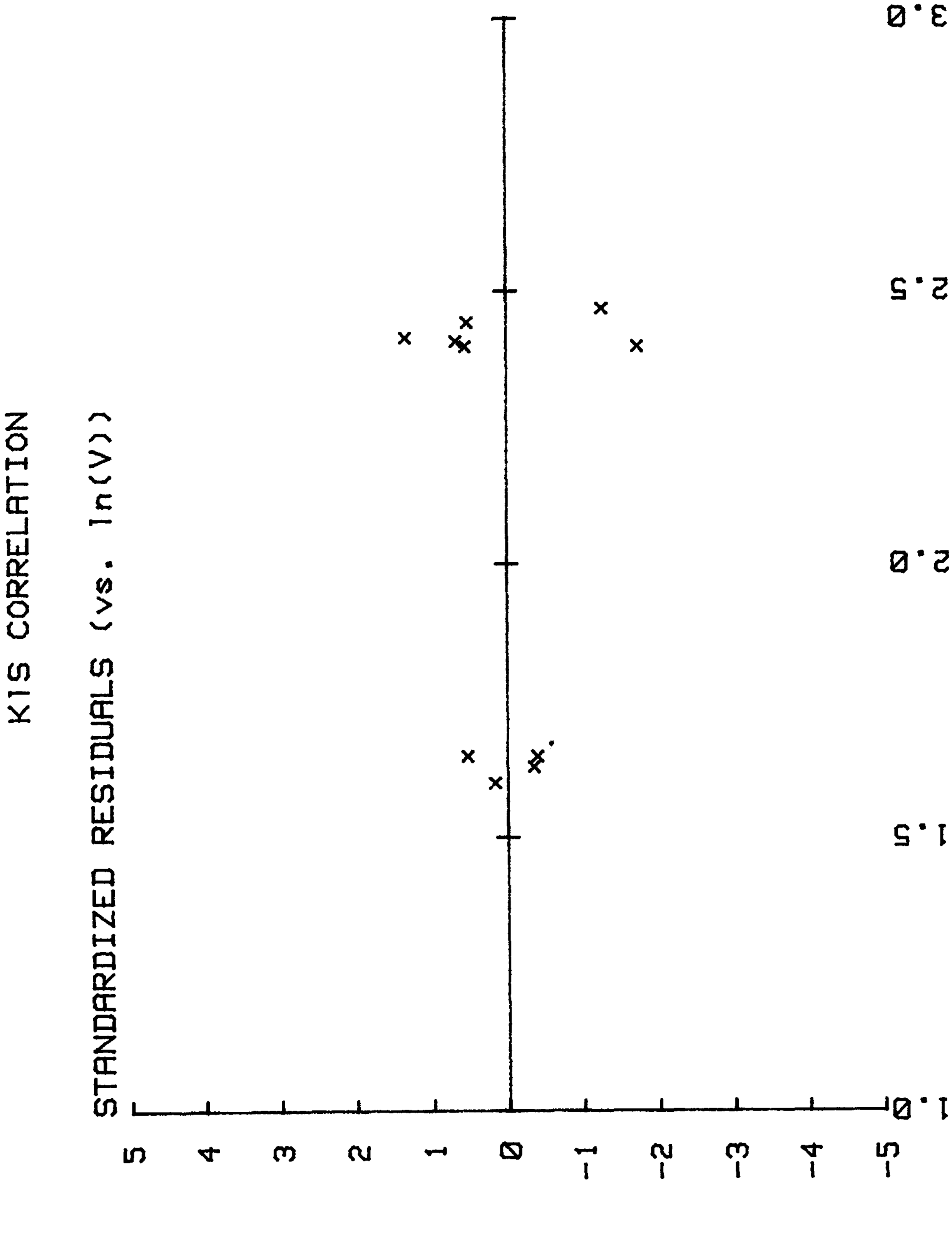
SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F-VALUE
TOTAL	9	2.51415		
REGRESSION	1	2.04590	2.04590	34.95
X^1	1	2.04590	2.04590	34.95
RESIDUAL	8	.46825	.05853	

	REGRESSION COEFFICIENTS		STANDARD ERROR	
VARIABLE	STD. FORMAT	E-FORMAT	REG. COEFFICIENT	T-VALUE
'CONSTANT'	-5.07935	-.507935119703E+01	.42253	-12.02
	1.16693	.116692966129E+01	.19738	5.91

		95 % CONFIDENCE INTERVAL	
	COEFFICIENT	LOWER LIMIT	UPPER LIMIT
'CONSTANT'	-5.07935	-6.05396	-4.10474
X^1	1.16693	.71166	1.62220

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	-2.10455	-2.22930	.12475	.51564	
2	-2.50593	-2.19925	-.30667	-1.26760	
3	-2.10949	-2.27062	.16113	.66600	
4	-1.93864	-2.26224	.32360	1.33756	
5	-3.02826	-3.15548	.12723	.52588	
6	-3.26231	-3.17814	-.08416	-.34788	
7	-3.25192	-3.15548	-.09643	-.39860	
8	-2.15072	-2.28118	.13045	.53921	
9	-2.70157	-2.28118	-.42040	-1.73766	
10	-3.17247	-3.21298	.04051	.16744	


KIS CORRELATION
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
1.0
1.5
2.0
2.5
3.0
ln(KIS)
ln(V)


KIS CORRELATION
STANDARDIZED RESIDUALS (vs. ln(V))
5
4
3
2
1
0
-1
-2
-3
-4
-5
1.0
1.5
2.0
2.5
3.0

GPO 845-554

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.